A physicist's view of the world's energy situation

Steven E. Koonin
Chief Scientist
BP, plc

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Outline

- A bit about BP

- Drivers of the energy scene

- Possible technology responses

"Physicist's view" =
first-principles, quantitative, analytic, descriptive

A bit about bp

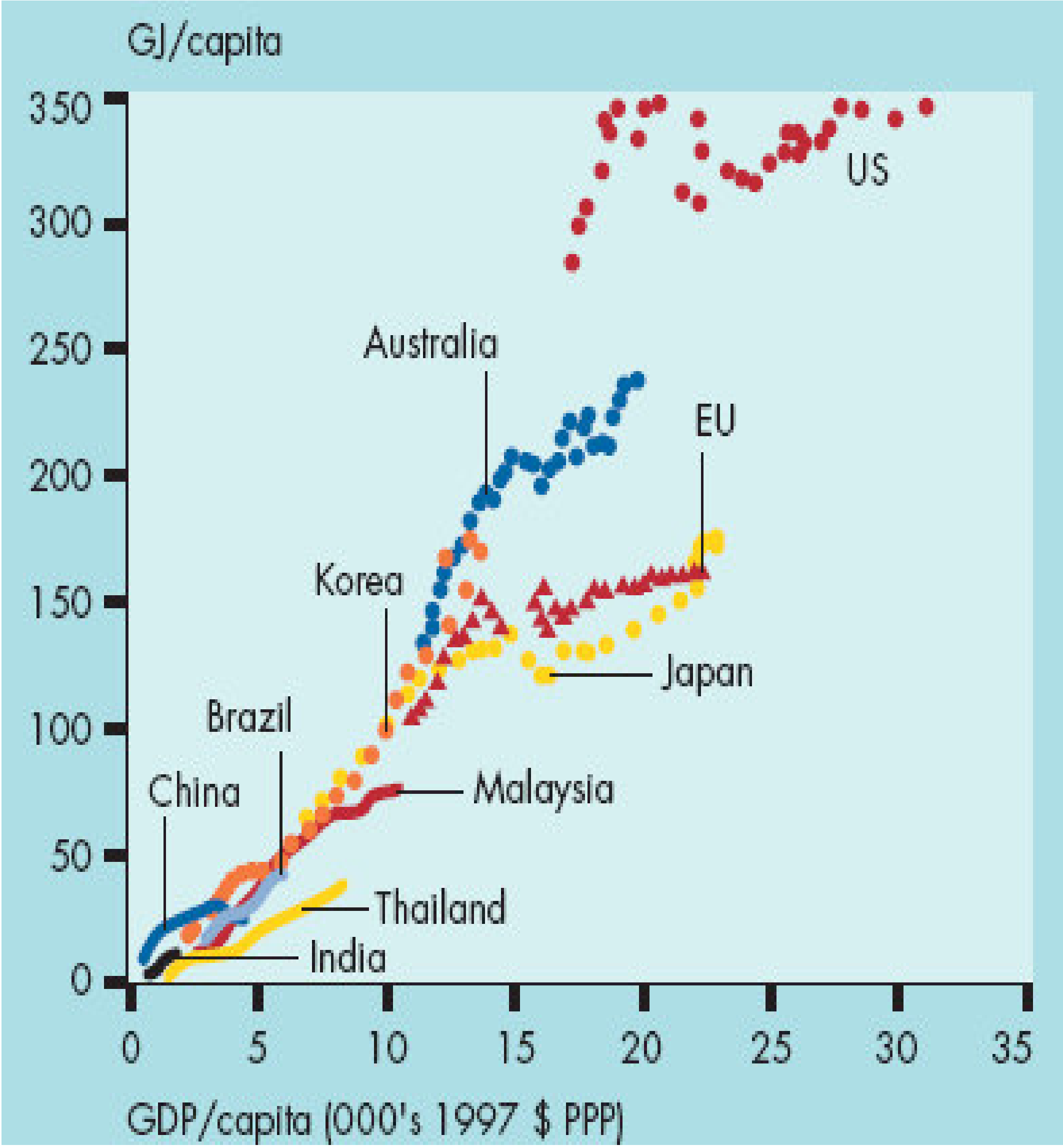
- **An integrated oil company**
  - Explore, Produce, Refine, Trade, Transport, and Sell oil/gas and related products (chemicals, lubricants)
  - 4 M bbl oil equiv per day (3% of world production), gas:oil ~ 40%
    - Alaska, GoM (DW), Trinidad, Angola, Caspian, Indonesia
  - Largest gasoline retailer in US
  - World's 3rd-largest solar company
  - Major foreign investor in Russia (~$7B)
- **Scale of the enterprise**
  - $230B/year revenue, $17B/year profit
  - ~110,000 people in most of world
  - 13 M customers/day at >30,000 retail outlets

five key drivers of the energy future

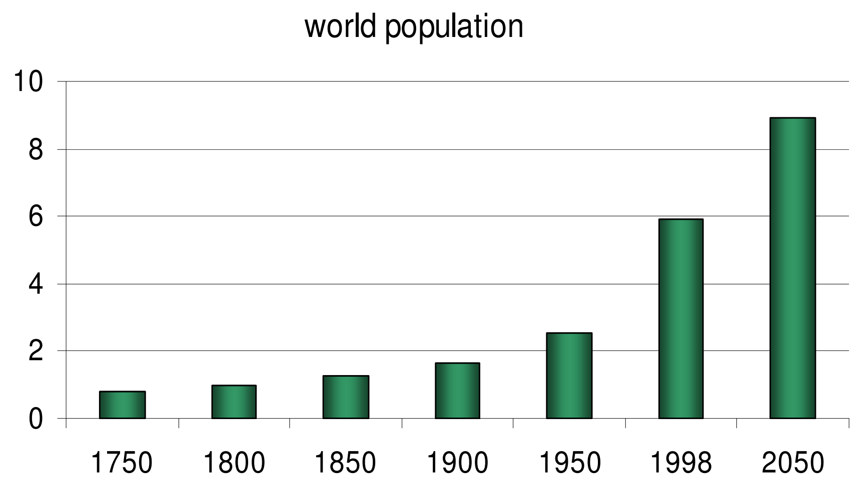
five key drivers of the energy future

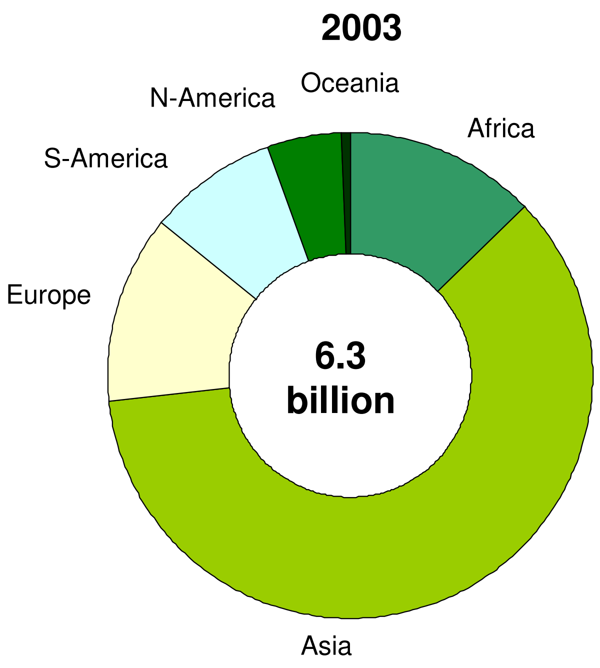
- rapid GDP growth esp. in developing countries
- growth of megacities
- changing customer preferences
- potential for demand side intervention

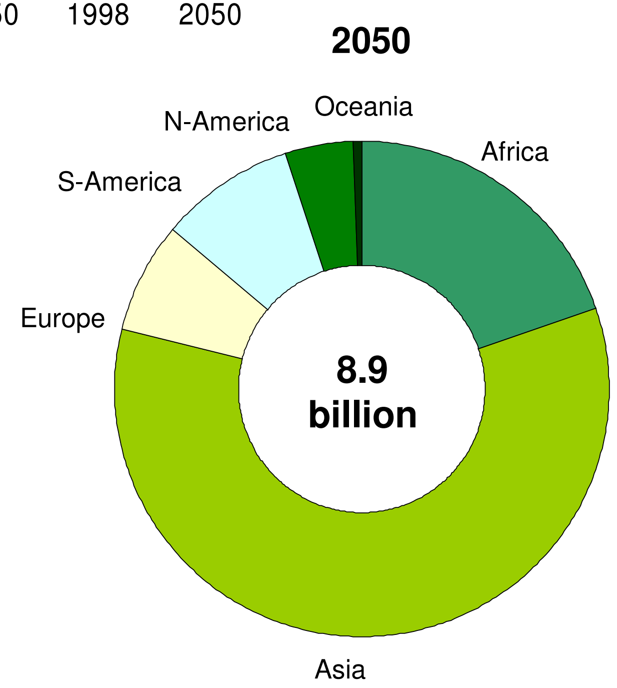
Energy use grows with economic development



Demographic Transformations



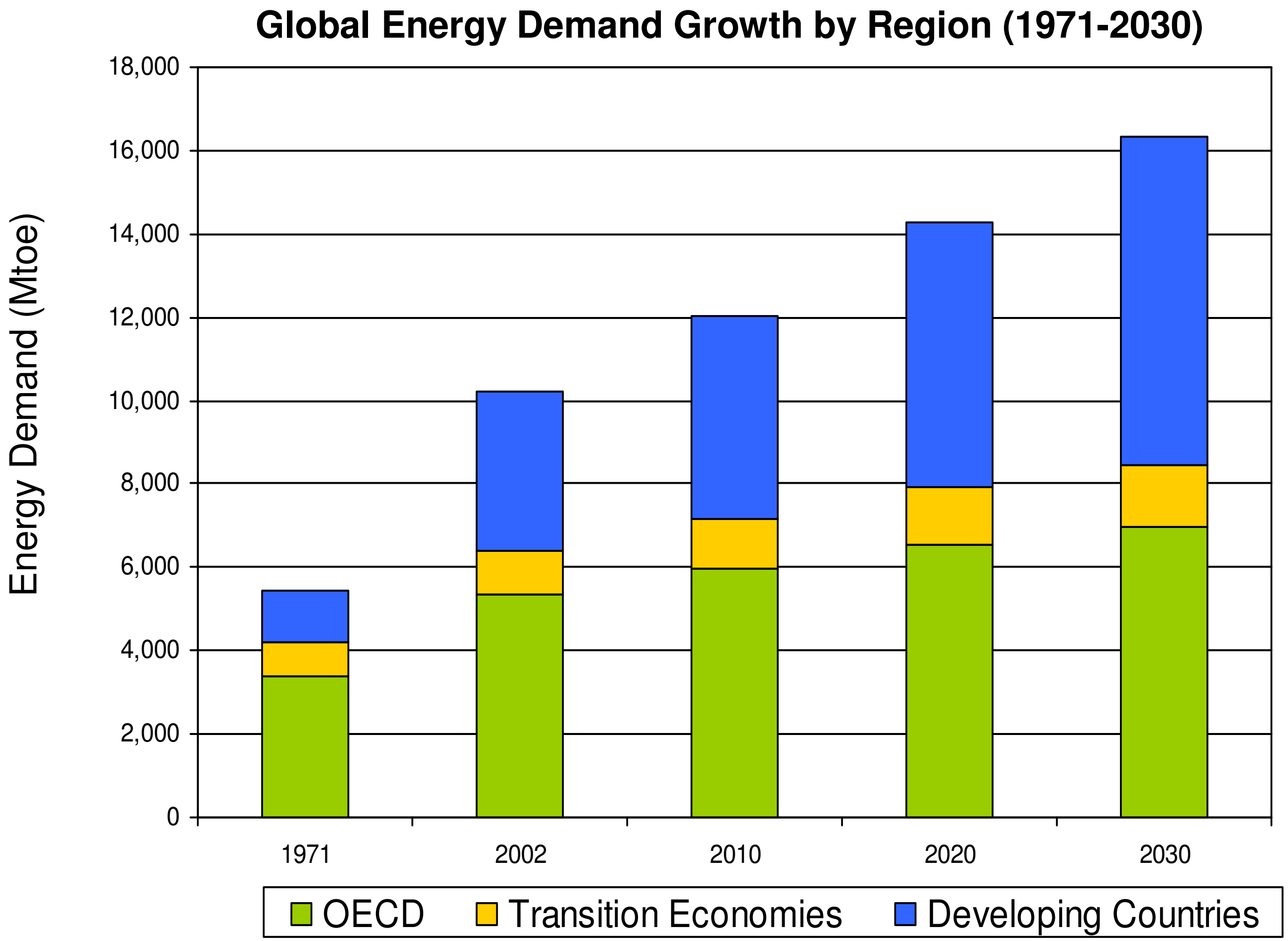




source: United Nations

energy demand – growth projections

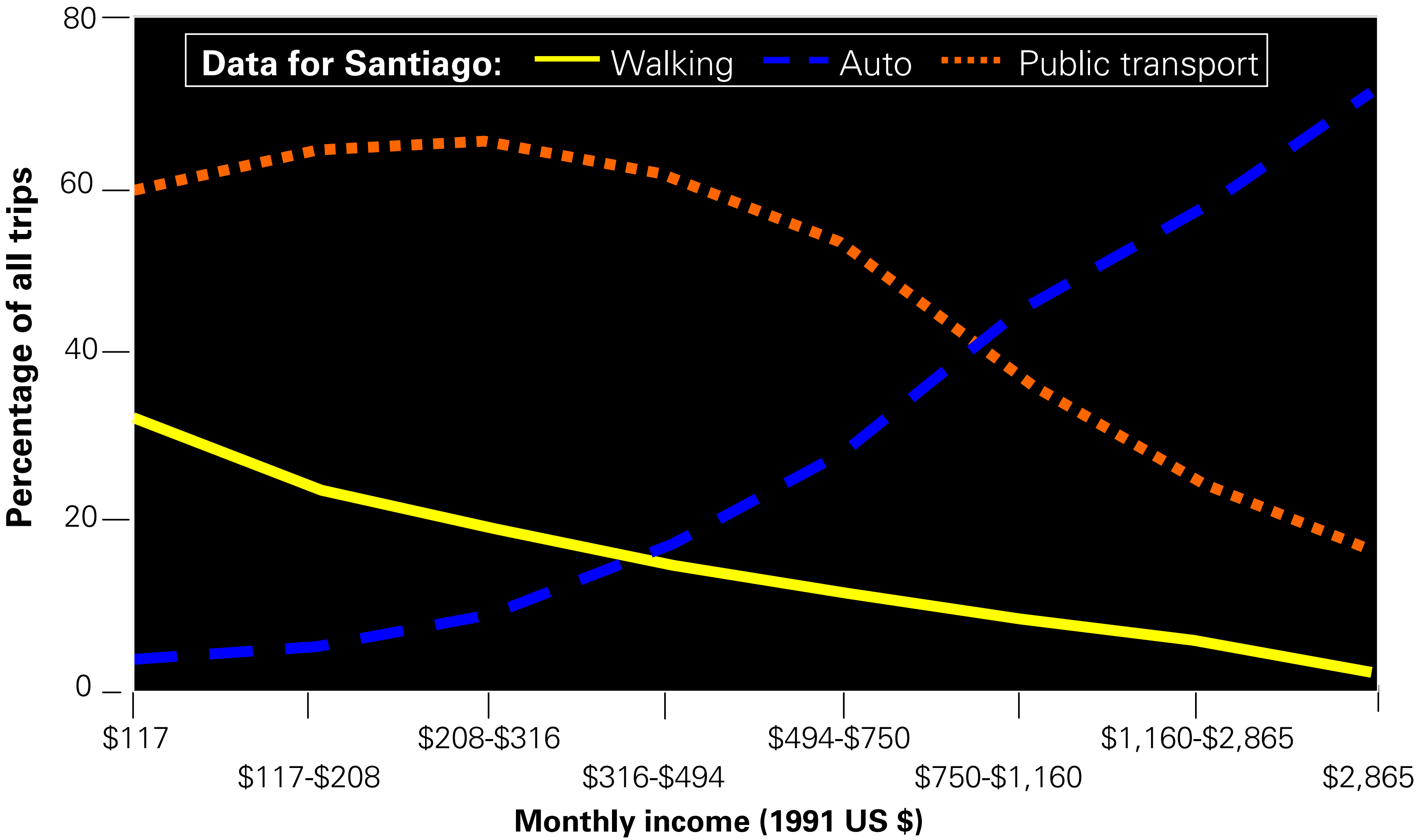
Global energy demand is set to grow by over 60% over the next 30 years – 74% of the growth is anticipated to be from non-OECD countries



Notes: 1. OECD refers to North America, W. Europe, Japan, Korea, Australia and NZ
2. Transition Economies refers to FSU and Eastern European nations
3. Developing Countries is all other nations including China, India etc.

Source: IEA World Energy Outlook 2004

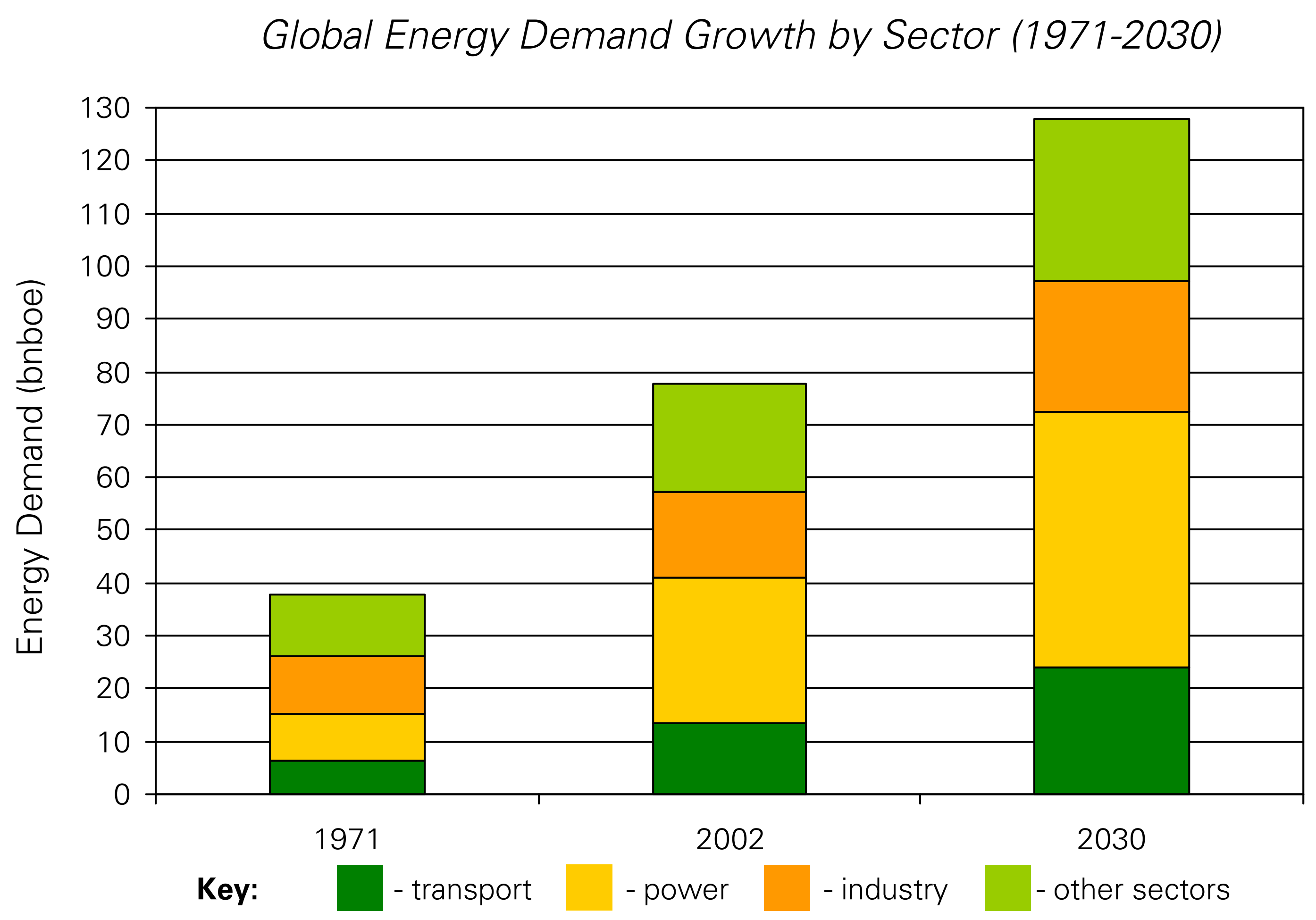
The Income Dependency of Mobility



Note: Santiago does not add to 100%; not all modal shares included

Source: Arve Thorvik, WBCSD, Sustainable Mobility

growing energy demand is projected



Notes: 1. Power includes heat generated at power plants
2. Other sectors includes residential, agricultural and service

Source: IEA WEO 2004

A word about energy efficiency

- Demand depends upon more than GDP
  - Geography, Climate
  - Technology
  - Economic mix
  - Lifestyle choices
    - US = 3X Japan for transport
- Efficiency through technology is about paying today vs. tomorrow
  - Must be cost effective
  - May <u>not</u> reduce demand
- Non-obvious places may have large potential savings

German energy use, 2001

Energy Services

Heated Rooms
(3280 Mrd m²)

Industrial Products
(40 Mio t steel)

Mobility
(917 Mrd Pass.km)
(509 Mrd tkm)

Automation, Air Pressure, Cooling

Illuminated Areas
(in m²)

PC-, Phone- and Internet Use

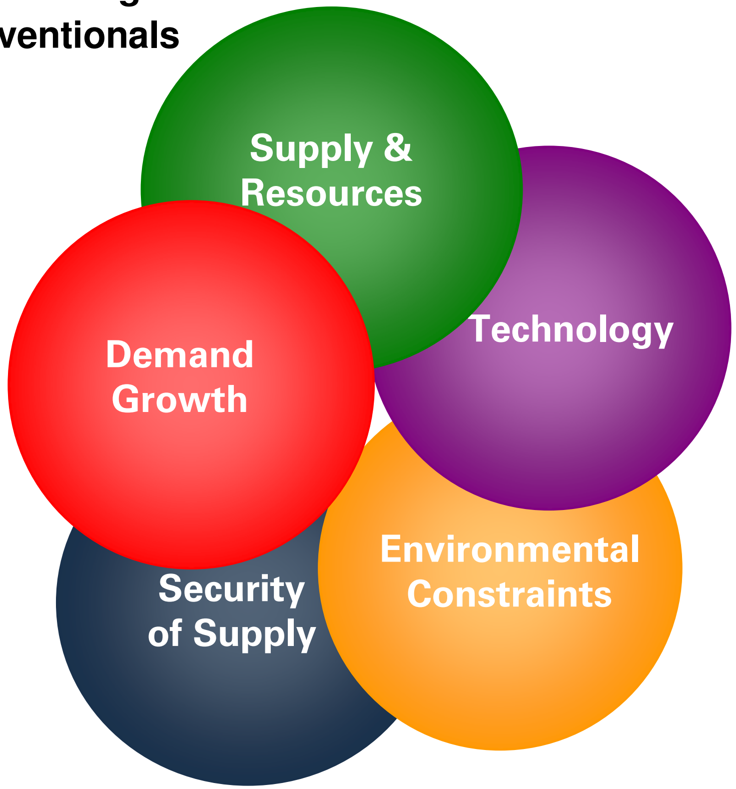
Useful Energy of Final Energy Sectors

	PJ	Conversion Efficiency (%)
Space Heat	2.451	76,5
Process Heat	1.348	57,4
Motive Power	518	19,5
Other Drives	552	59,7
Illumination	17	8,4
Information,. Communication	106	78,7

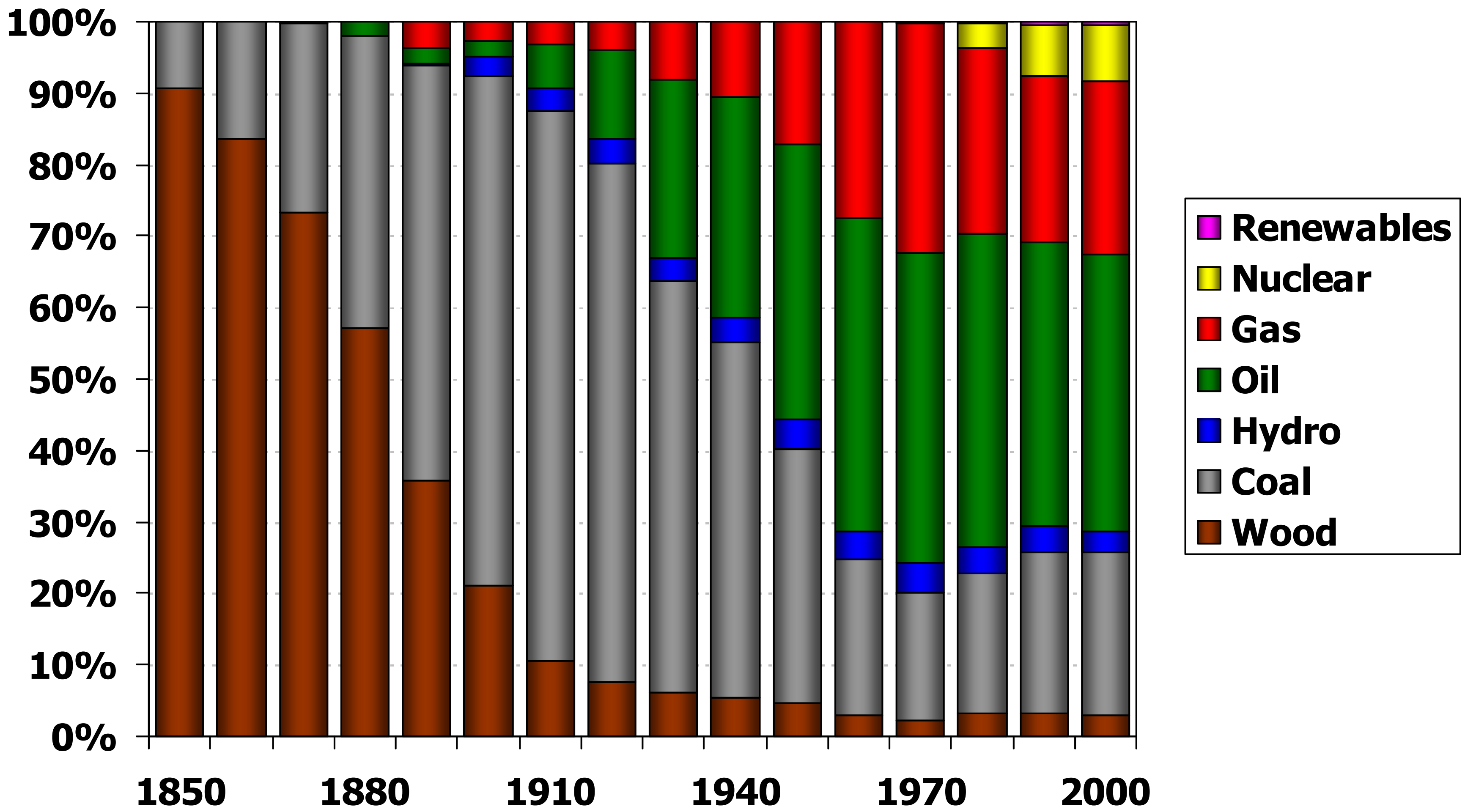
five key drivers of the energy future

- **significant hydrocarbon resource potential**
- **misalignment between resource location and demand**
- **growing supply challenges**
- **growth of unconventionals**

- rapid GDP growth esp. in developing countries
- growth of megacities
- changing customer preferences
- potential for demand side intervention



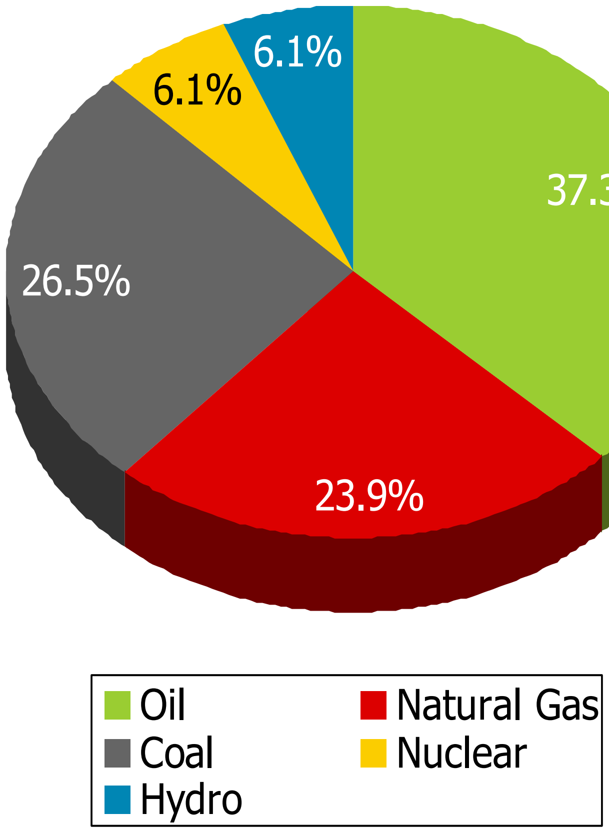
US energy supply since 1850

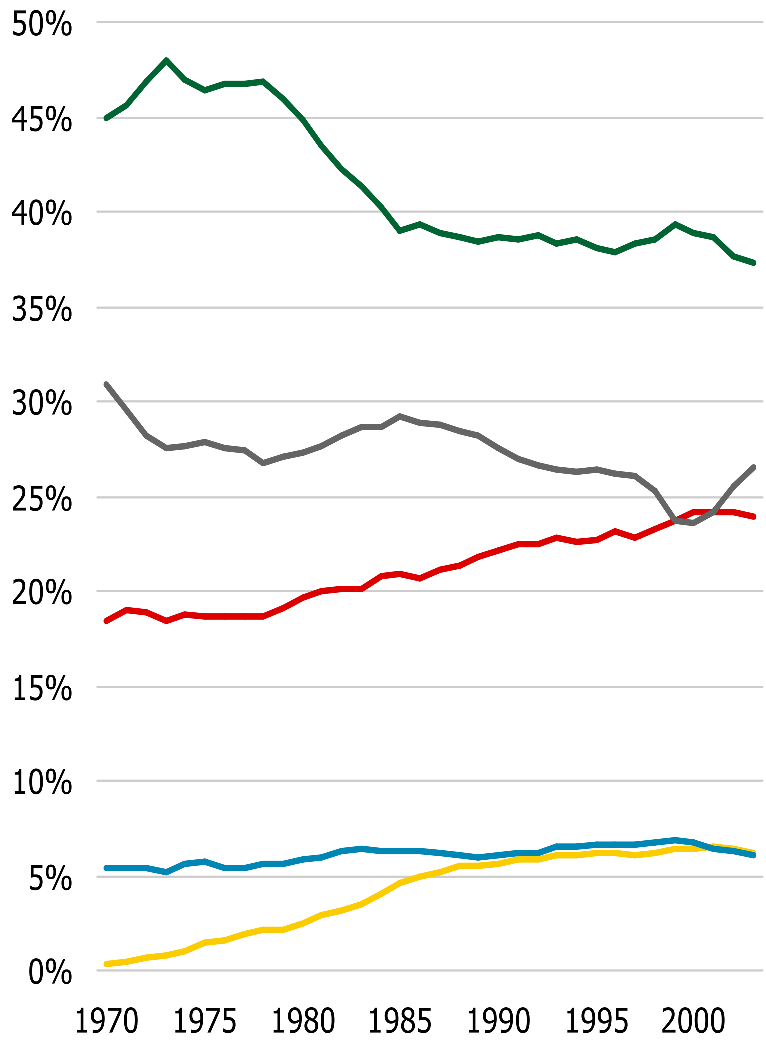


Source: EIA

current and historical global energy mix

Current global energy supply is dominated by fossil fuels – oil has been the largest component of the energy mix for many decades; gas has grown strongly since the 1970's; coal has been growing in the last four years; hydro is constant and nuclear has plateaued



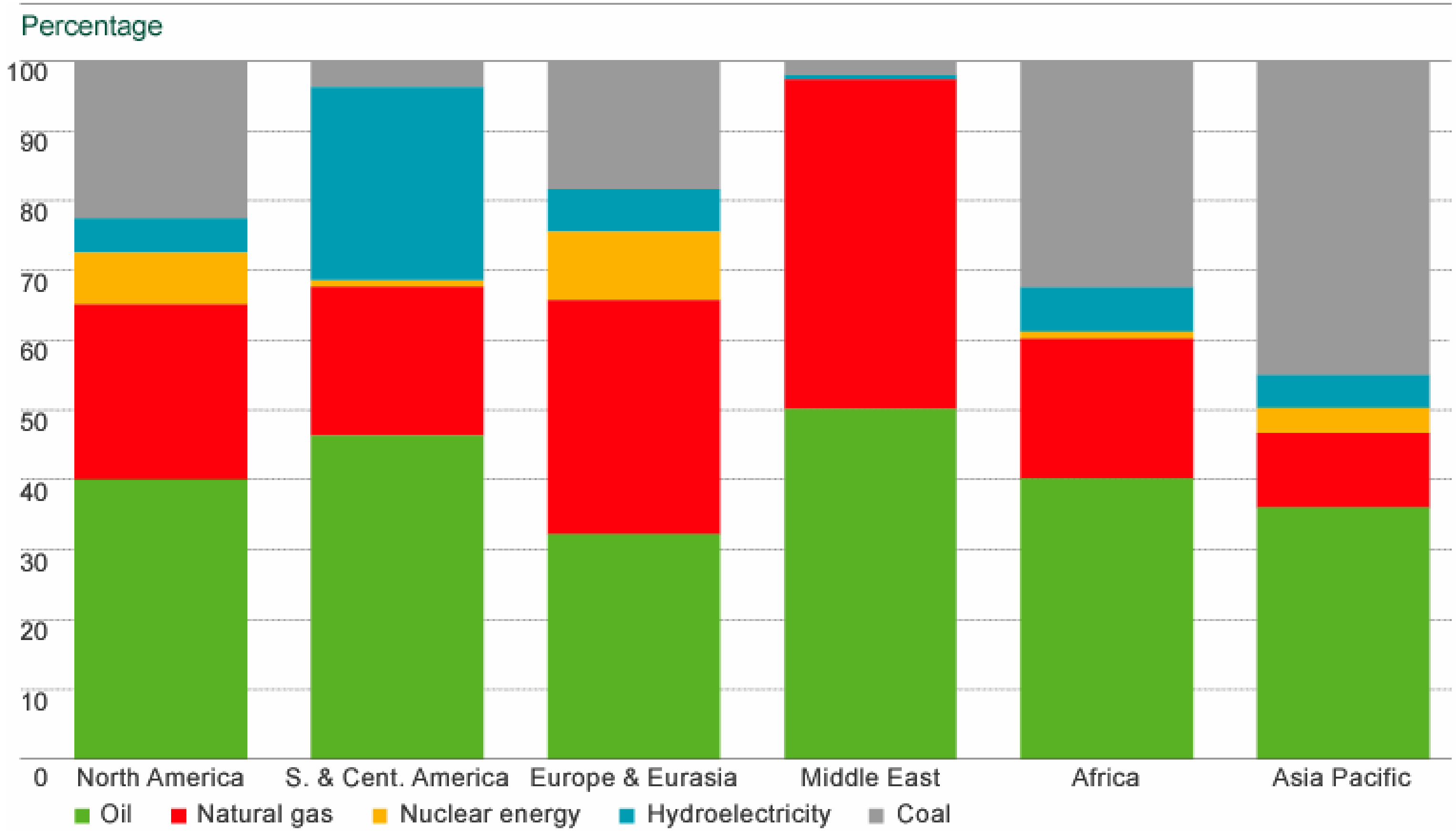


Source: BP Statistical Review

The three fossil fuels are quite different

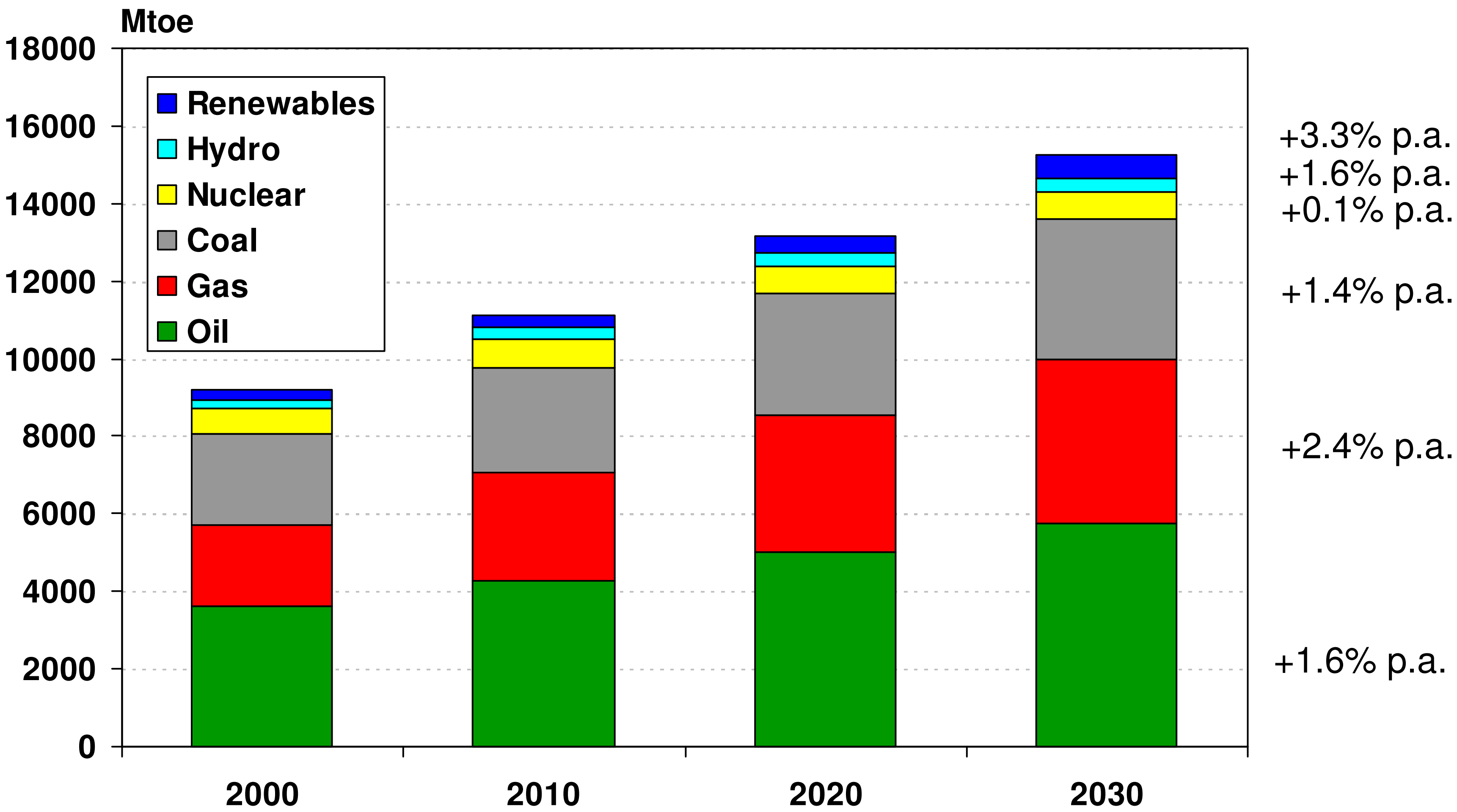
- **Oil**
  - Predominantly used for transportation (energy density!)
  - Medium energy content, varying impurities
  - Transportable (pipelines, tankers)
  - Largest resources in ME; global market
- **Gas**
  - Predominantly for stationary energy (heat, power)
  - Highest energy content, "cleanest"
  - Tougher to transport (pipelines, LNG)
  - Large resources in ME, Russia; emerging global market
- **Coal**
  - Predominantly for stationary energy
  - Lowest energy content, can be "dirty"
  - Transportable, but not significant international trade
  - Large resources in US, China, Russia

Regional primary energy consumption pattern 2003



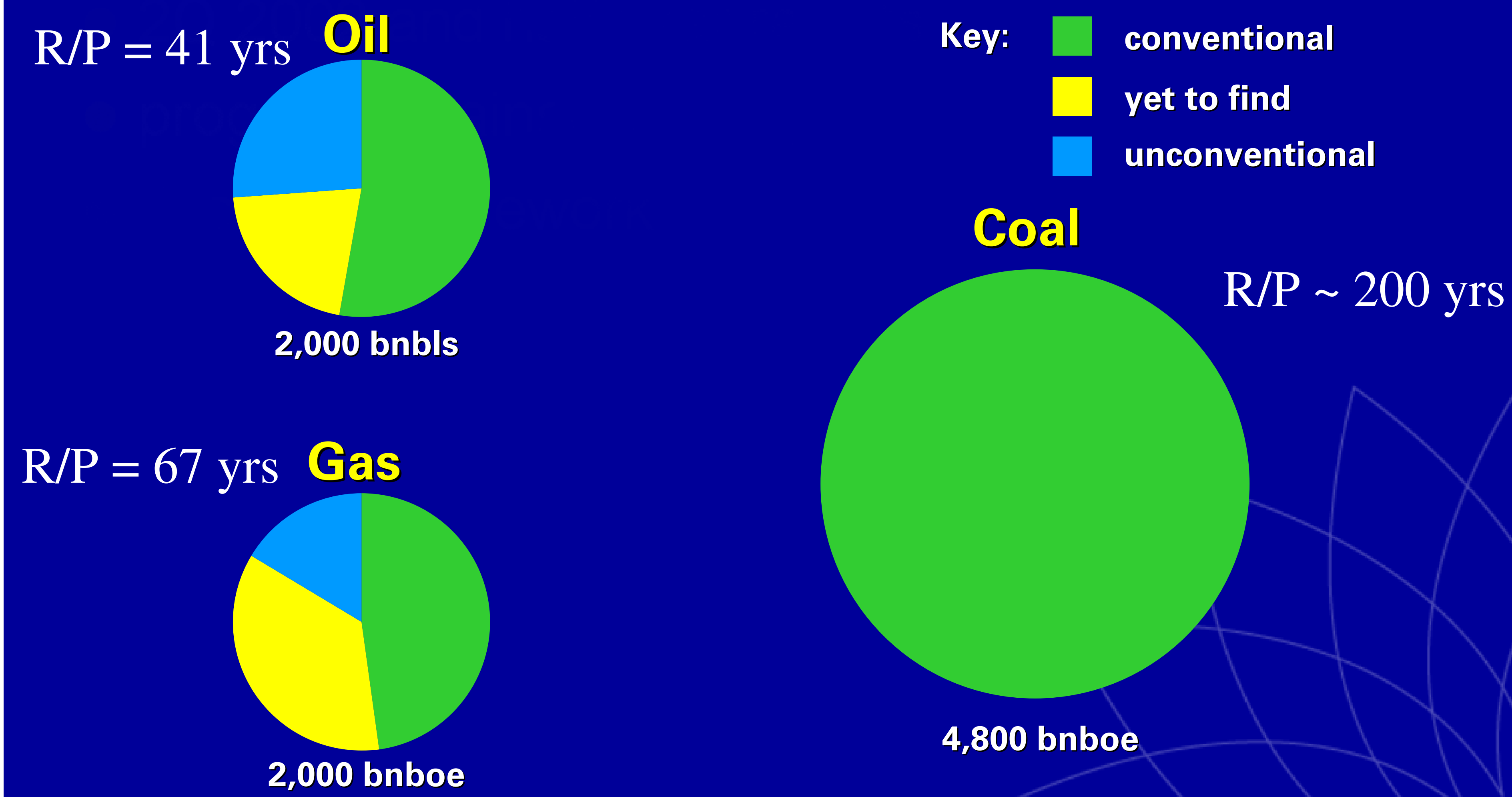
Oil remains the largest single source of energy in most parts of the world. The exceptions are the Former Soviet Union, where gas dominates and Asia Pacific where coal is the dominant fuel.

“Business as usual” energy supply forecast



Source: IEA WEO 2002

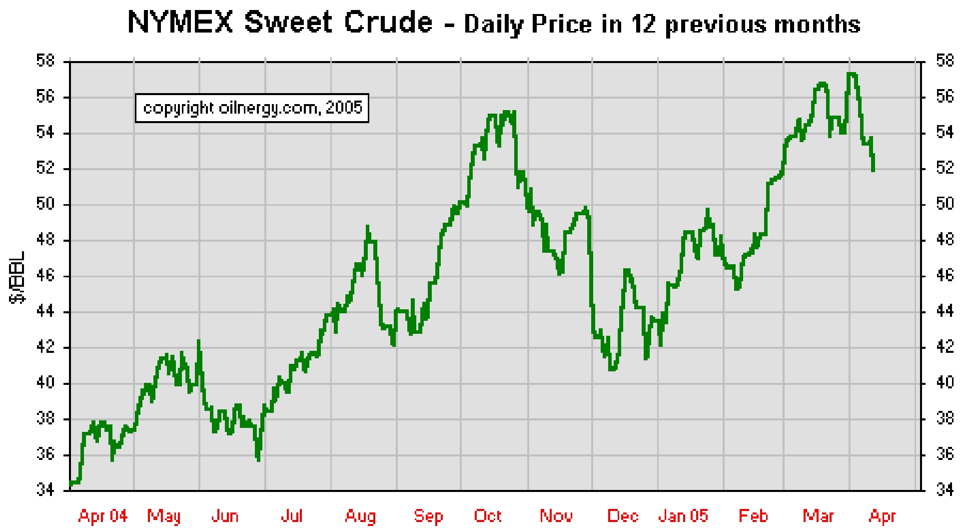
remaining global fossil resources



Source: BP estimates

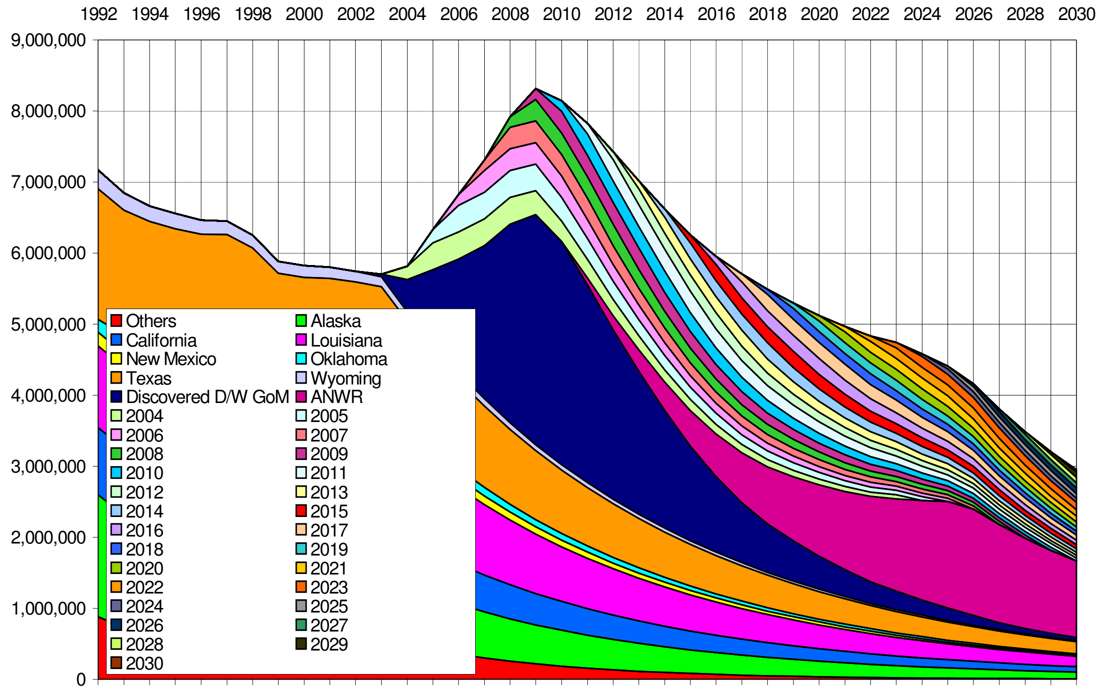
About oil prices

- **Oil production is 84 Million bbl/day = 30 Billion bbl/yr**
  - OPEC production ca 25 Million, Saudi ca 10 Million
  - US consumes 20 Million bbl/day
- **Historically, OPEC spare capacity was the buffer**
  - Keep price high enough to ensure cash flow
  - Keep price low enough to discourage conservation or fuel switching
- **Spare capacity now gone**
  - Surging demand (China +15% last year)
  - Underinvestment in unstable regions of the world
- **Small perturbations affect the market**
  - Angola, Venezuela strikes
  - GoM hurricanes
  - Russian Yukos troubles, ...



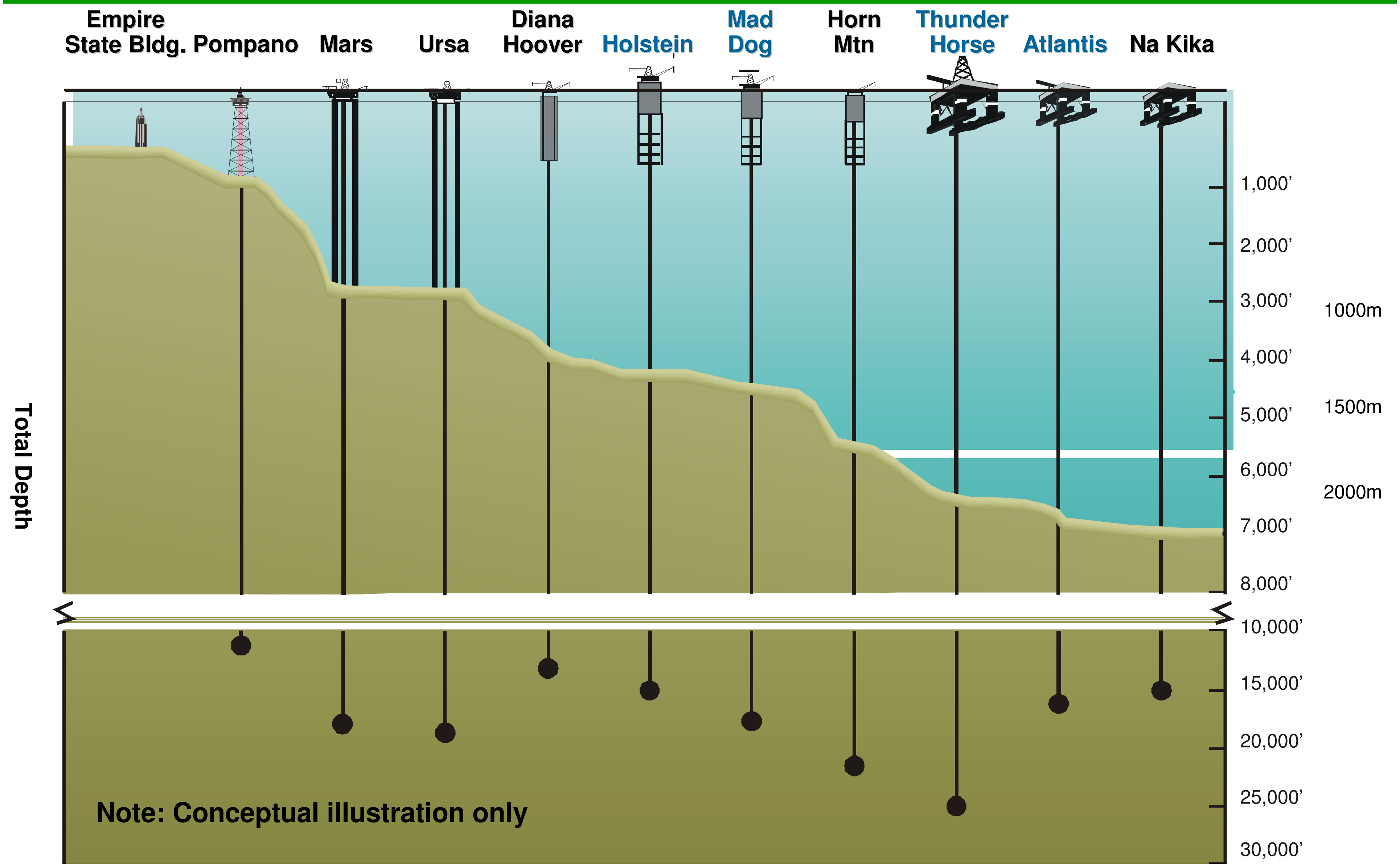
Will we run out?

- Geologist's view (Hubbert and all that)
  - Fossil resources are finite
  - Bigger fields are discovered and produced first
  - Fields come on rapidly and then decline slowly
  - Production peaks when ½ the resource has been consumed
  - Non-OPEC within 20 years? OPEC within 30 years?
- Economist's view
  - Price increases as demand exceeds supply
  - High prices will encourage discovery and production of more expensive resources
  - At some price, fuel substitution will be attractive
- Both are probably right



US oil production, 1992-2030

GoM Projects – the Move into Deeper Water

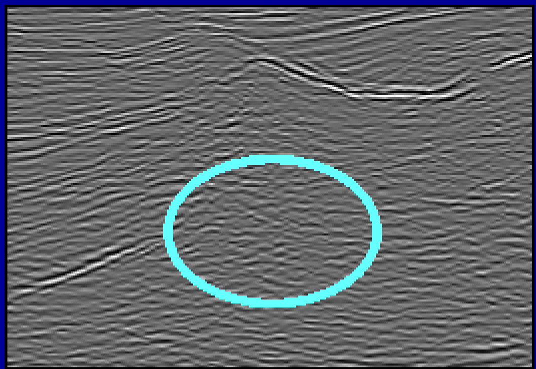


Deepwater projects

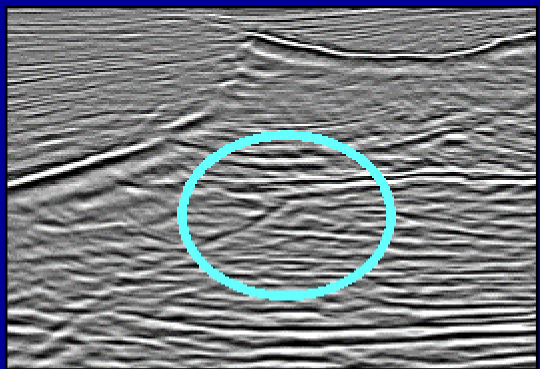
- 10^6 bbl/day for bp by 2006
- Scale is \$1-2B/project
- Drilling is expensive (~\$50M/hole)
- Problems include
  - Imaging the reservoir through salt
  - Extreme reservoir depths (Thunderhorse at 27,000' total depth)
  - High temperature and high pressure of reservoir fluids (Thunderhorse is 18,000 psi, 275 F, and corrosive
  - Marine environment creates integrity challenges (risers, wellheads, …)

subsalt seismic imaging

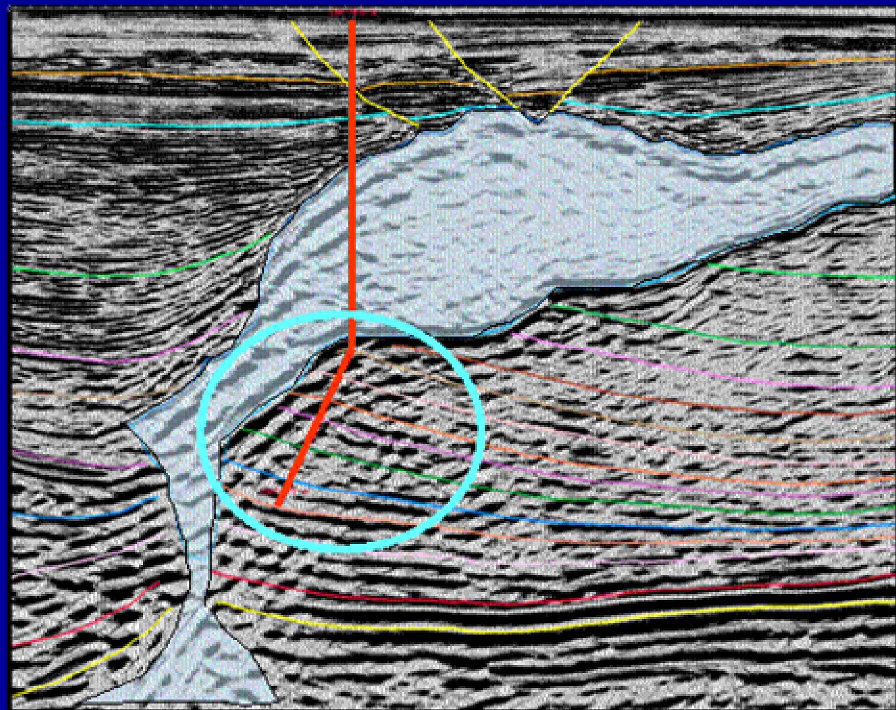
1999 - a hint



2001 - prospect leased



2003 - discovery

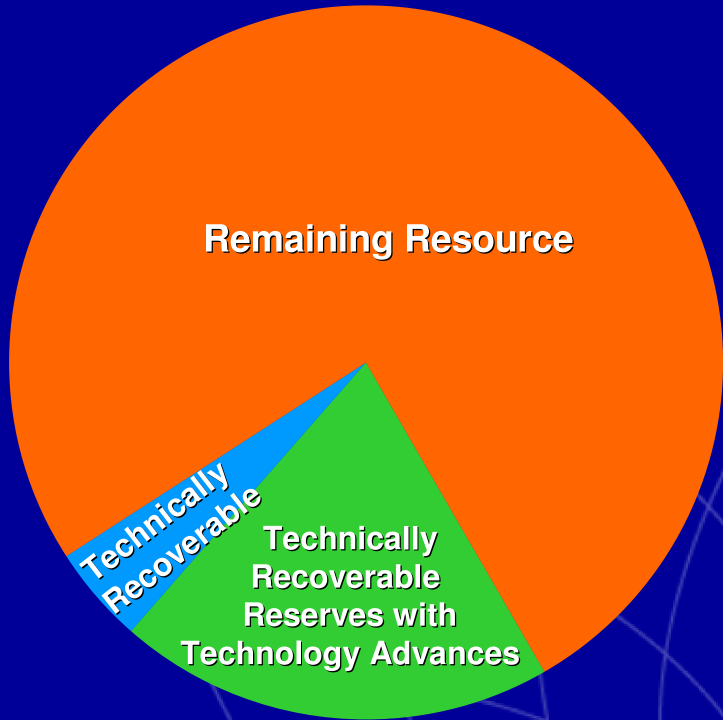


data reprocessed using
BP Common Azimuth Algorithm

Heavy oil is a future source of energy

Venezuelan Extra Heavy Oil

1.3 trillion barrels of oil in place



BP has 16.67% stake in Cerro Negro

…technology is the key to unlock the enormous potential

Coal/Gas/Biomass to liquids a possible future source of fuels

"Synfuel" GTL Technology (Gas To Liquids)

Natural Gas

Coal

Biomass

→ **Syngas Production** → **Fischer-Tropsch Reactor** → **Fischer-Tropsch Diesel**

$CO + H_2$

C_nH_{n+2}

Products have:

- **high Cetane number**
- **sulfur free**
- **aromatics free**


BP GTL Plant Alaska

five key drivers of the energy future

- significant hydrocarbon resource potential
- misalignment between resource location and demand
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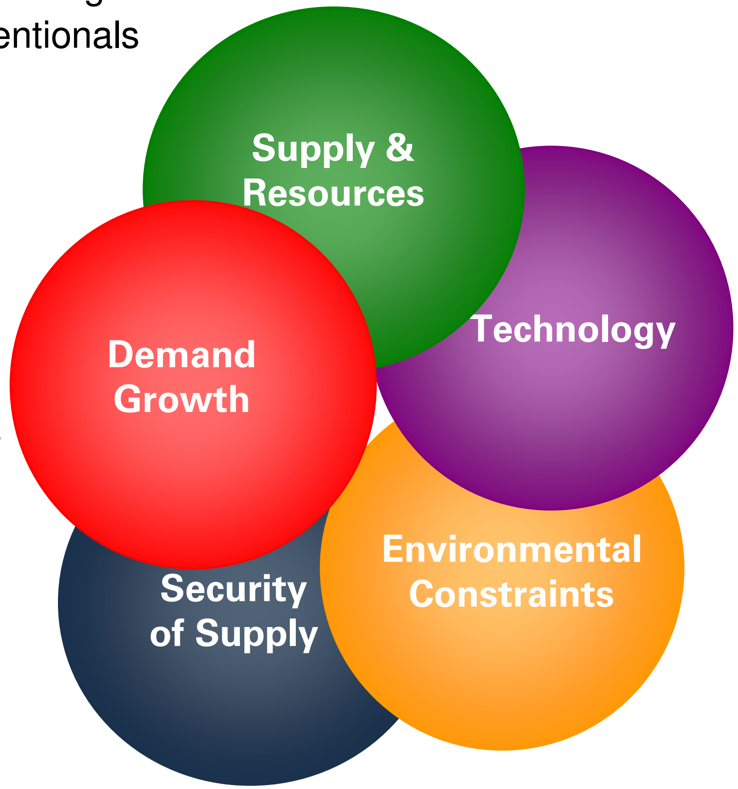
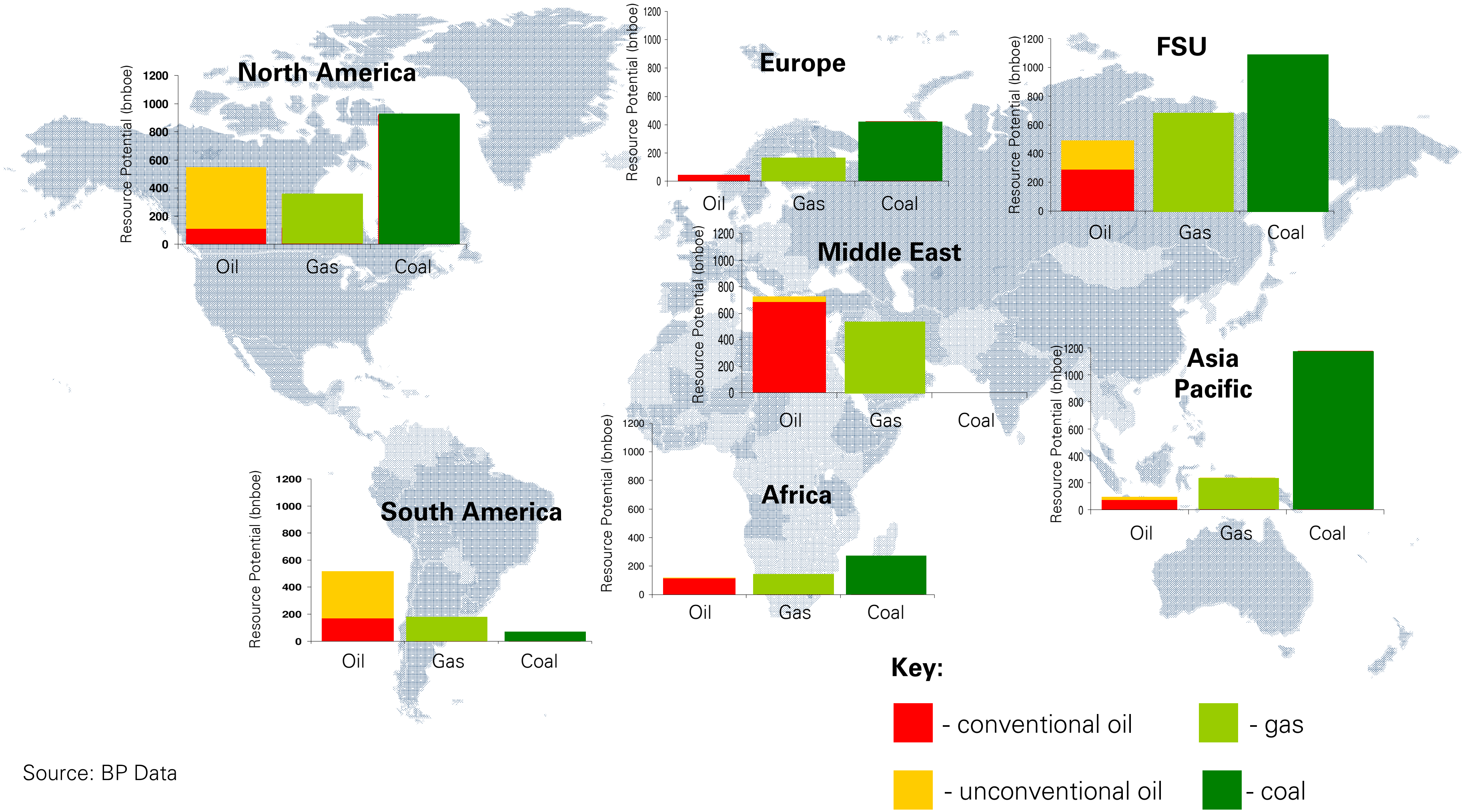


- rapid GDP growth esp. in developing countries
- growth of megacities
- changing customer preferences
- potential for demand side intervention

- **governance failures in producing countries**
- **significant rise in import dependence**
- **new policy initiatives to enhance energy security**
- **growing competition for energy resources**

significant hydrocarbon resource potential

Oil, Gas and Coal Reserves by Region (bnboe)

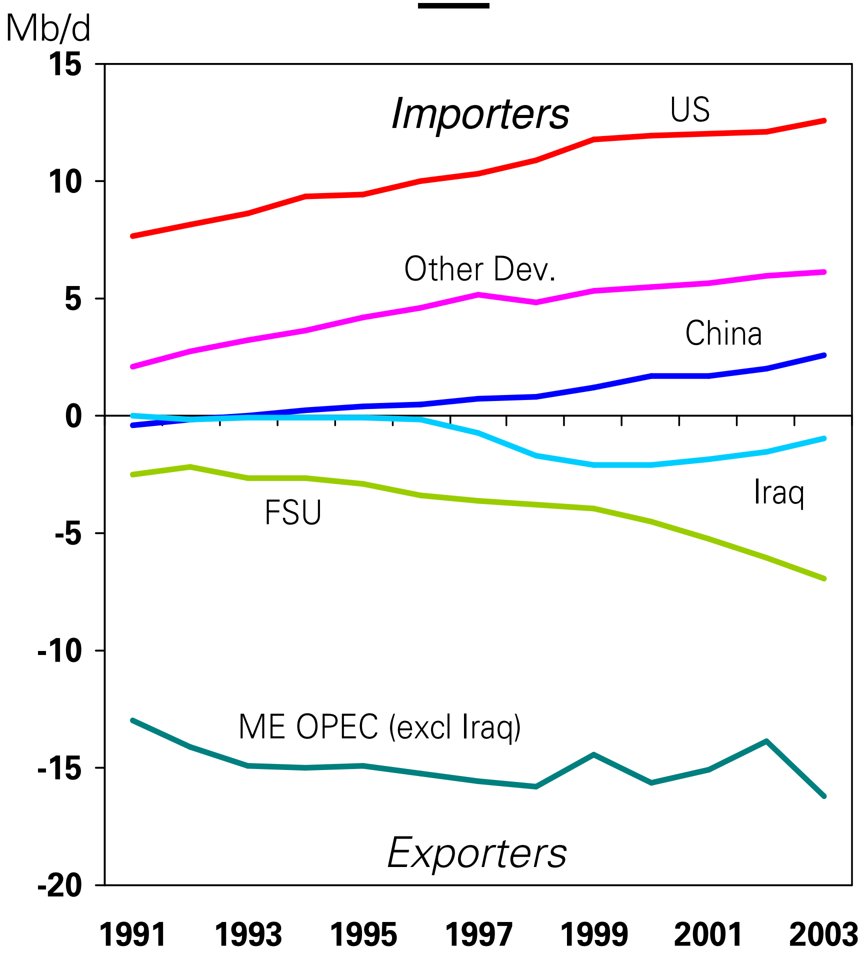


Source: BP Data

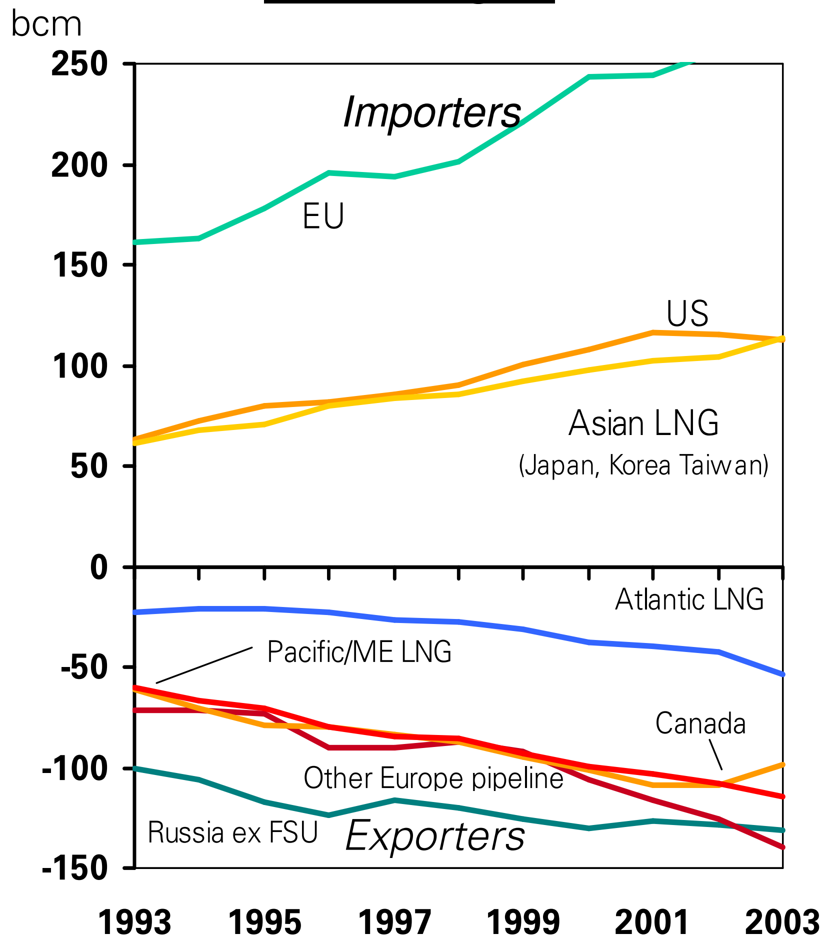
energy security - import dependence

Import dependence is rising in all the key markets; oil and gas production is also shifting increasingly away from OECD countries to non-OECD

Oil



Natural gas



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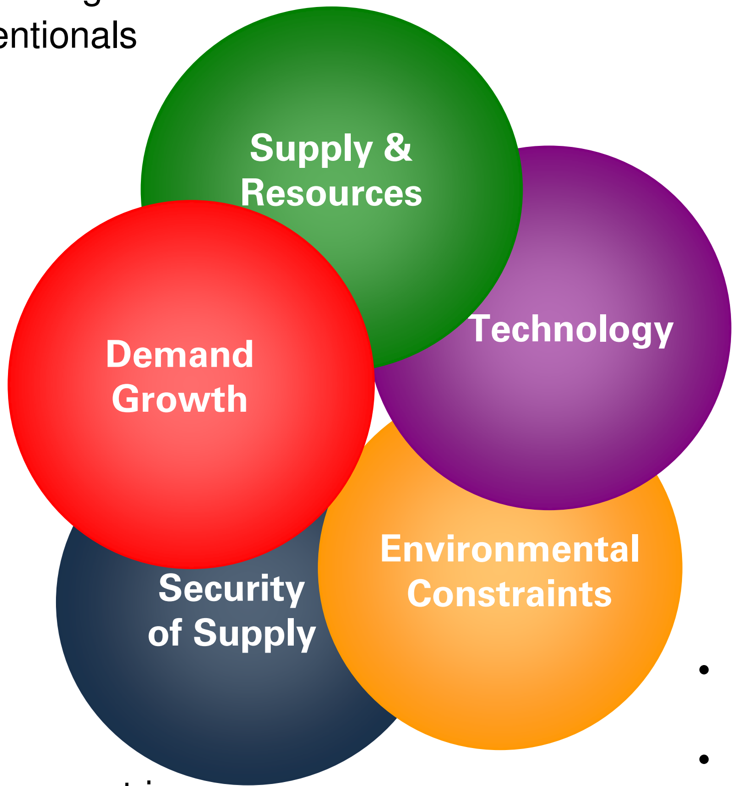

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- growing competition for energy resources

- **climate change and potential for carbon constraints**
- **tightening of regulation relating to local pollution**
- **increasing scrutiny for extractive industries**

Climate change and CO_2 emissions

CO_2 concentrations are rising due to fossil fuel use

The global temperature is increasing

- other indicators of climate change

There is a plausible causal connection

- but the scientific case is not overwhelming (natural variability, forcings)

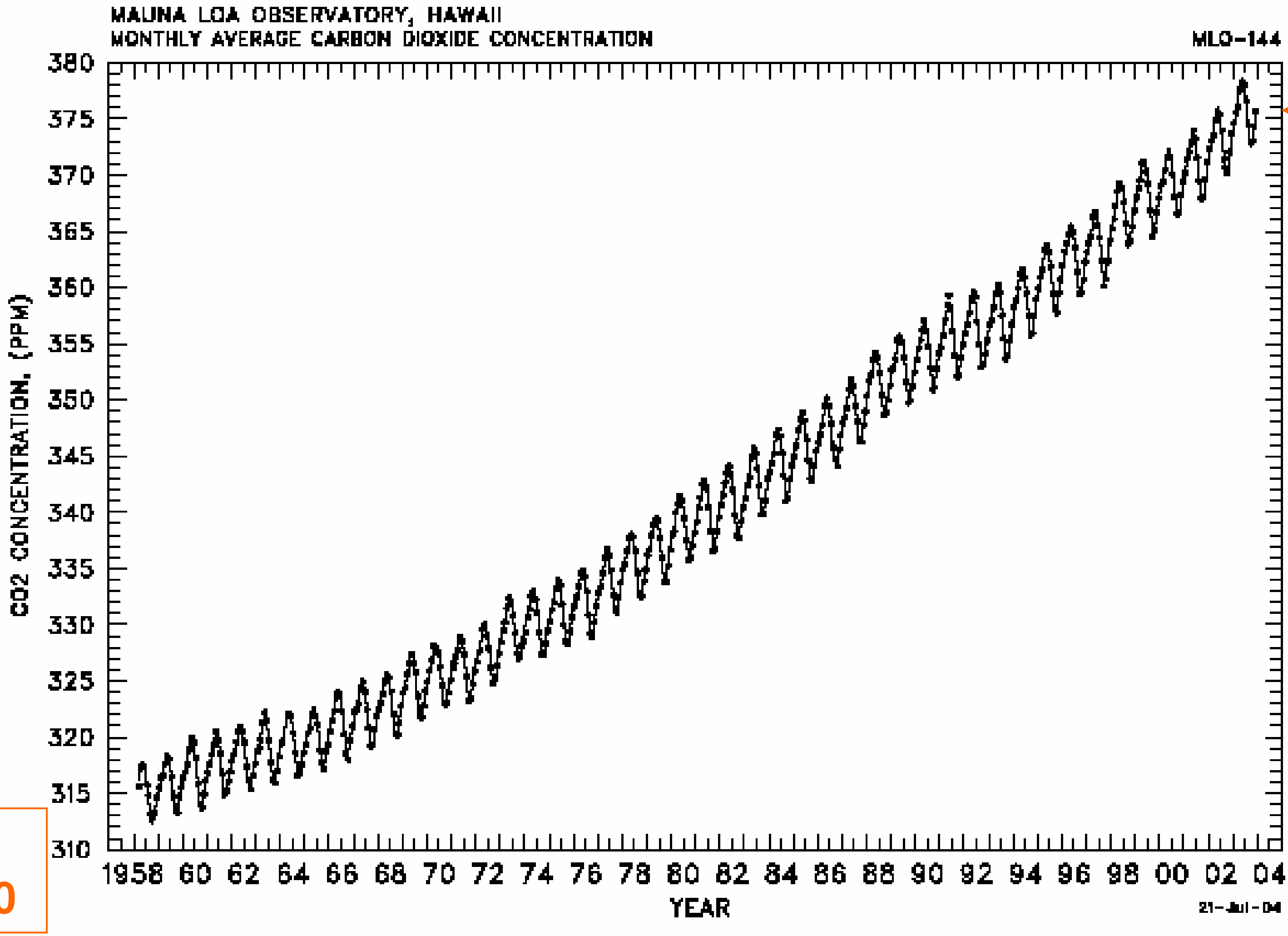
Impacts of higher CO_2 quite uncertain

- ~ 2X pre-industrial is a widely discussed stabilization target

Precautionary action is warranted

- What could the world do?
- Will we do it?

Anthropogenic increase of atmospheric CO_2

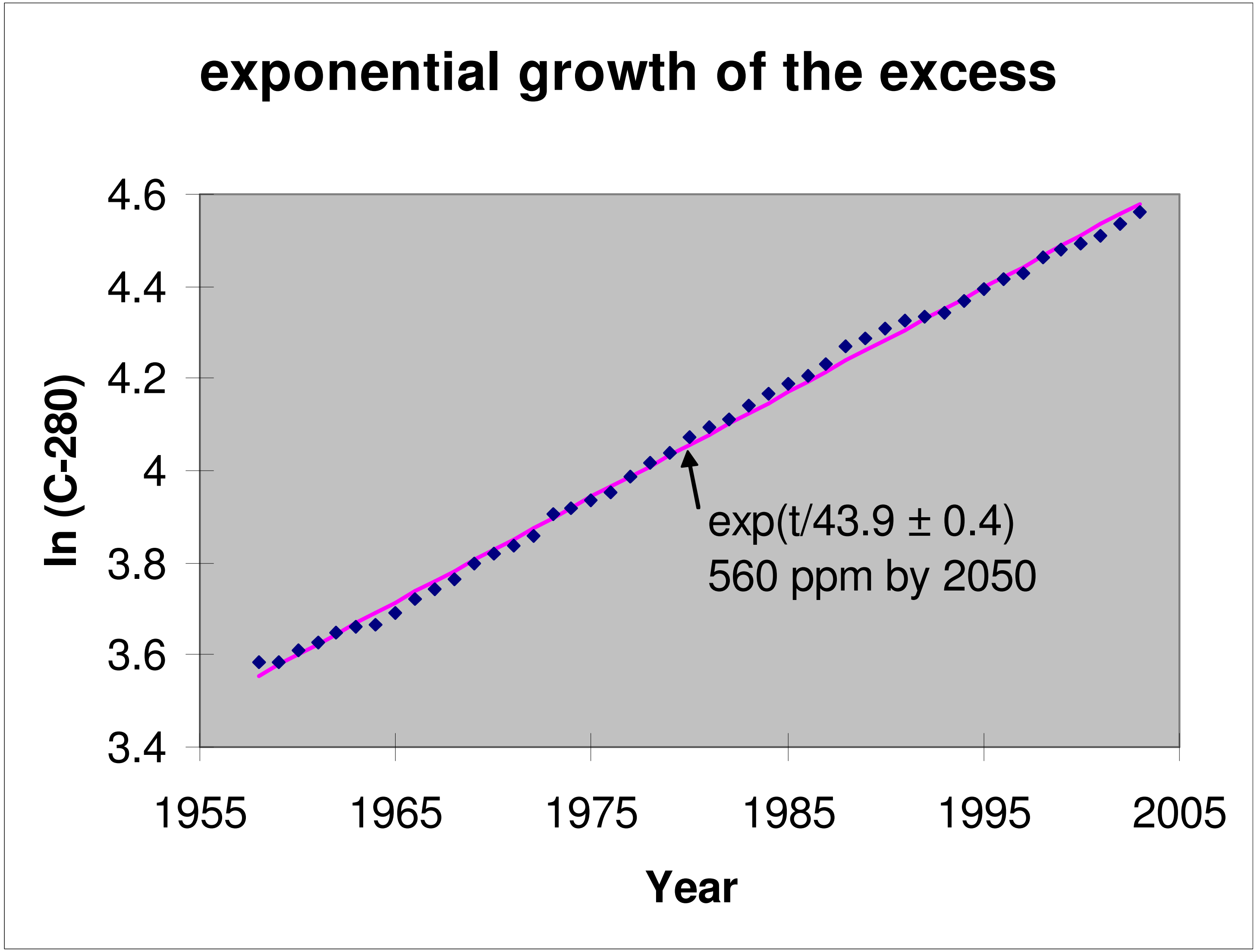


Now
C = 376

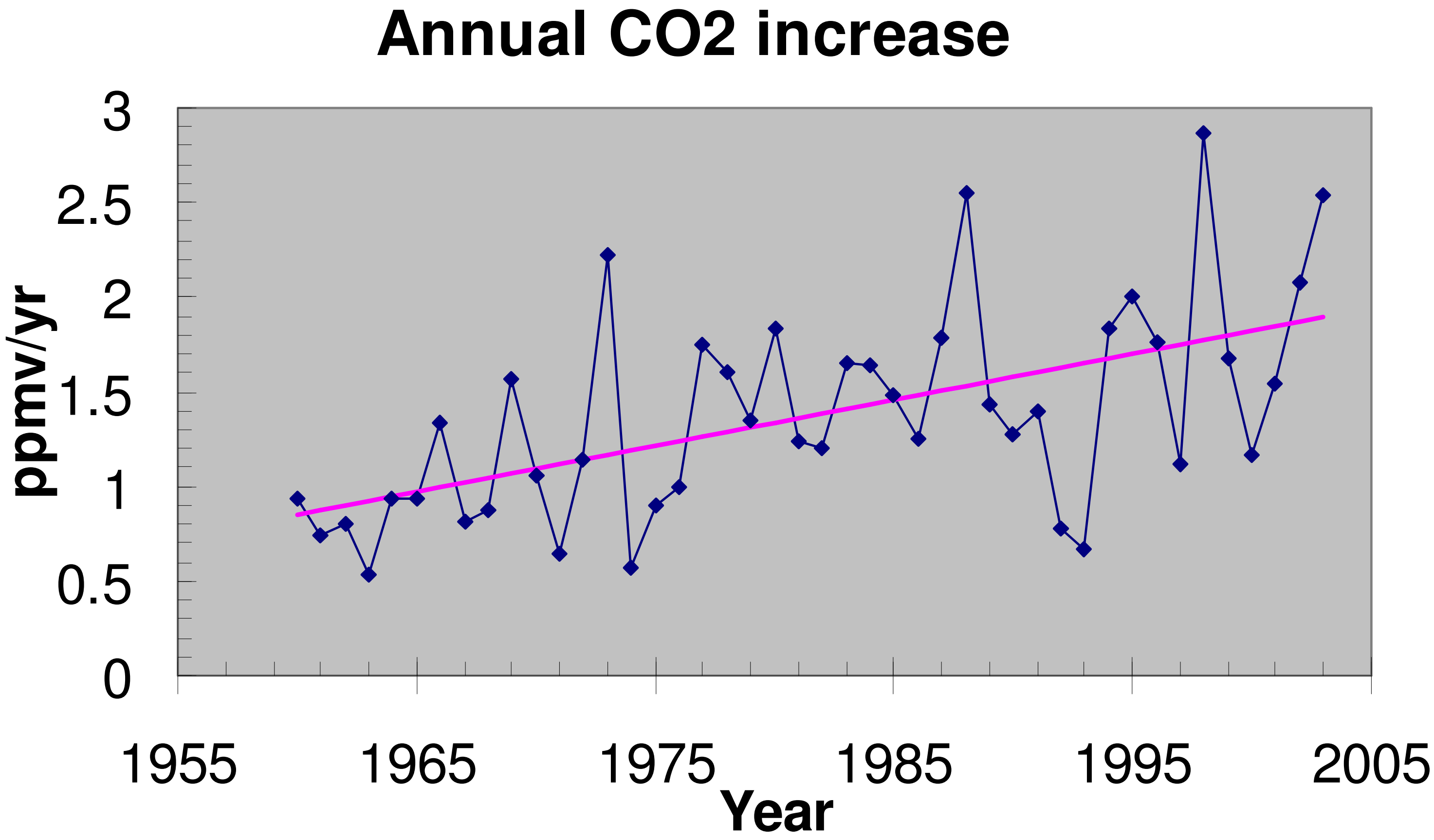
Was
C_0 = 280

- **1 ppm = 8 Gt CO2 = 2.2Gt C**

A simple extrapolation gives 45 years until the unsustainable level is exceeded

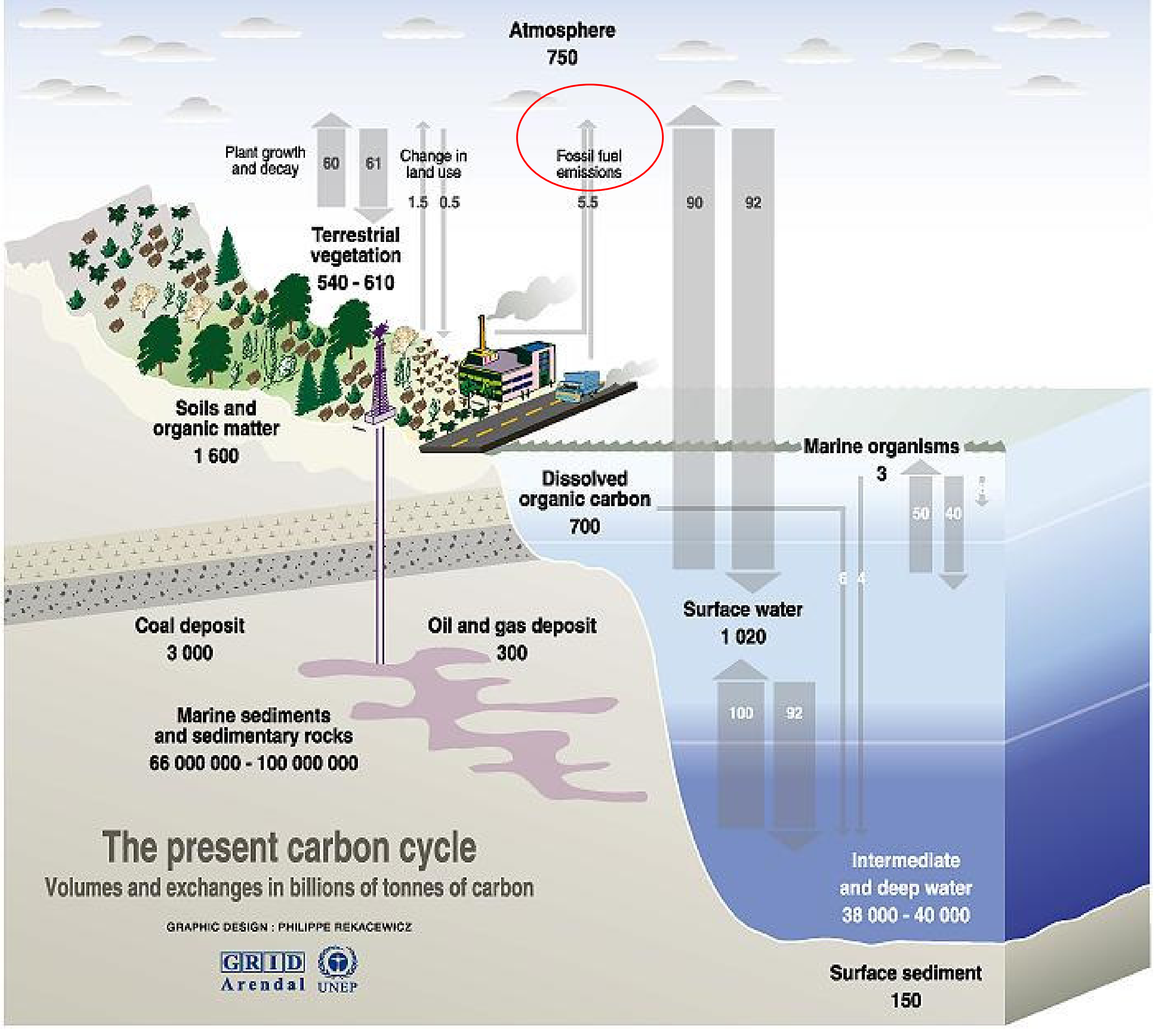


Annual CO_2 increases are themselves increasing

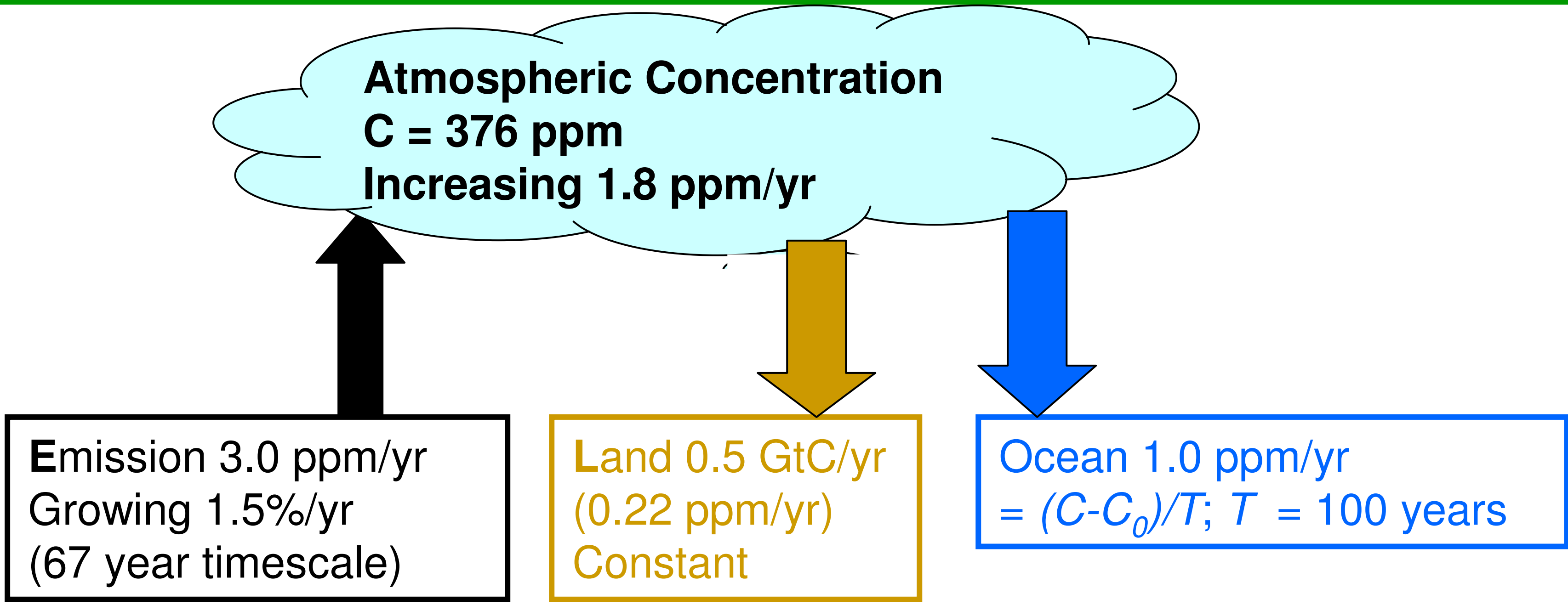


- **Rate of increase currently 1.8 ppm/yr**
  - **Increases by 0.24 ± 0.05 ppm/yr/decade**
- **But emissions are 3.0 ppm/yr**
  - **Hence land and ocean sinks are 1.2 ppm/yr**

Small anthropogenic perturbations to large and complex carbon fluxes



Construction of a simple model



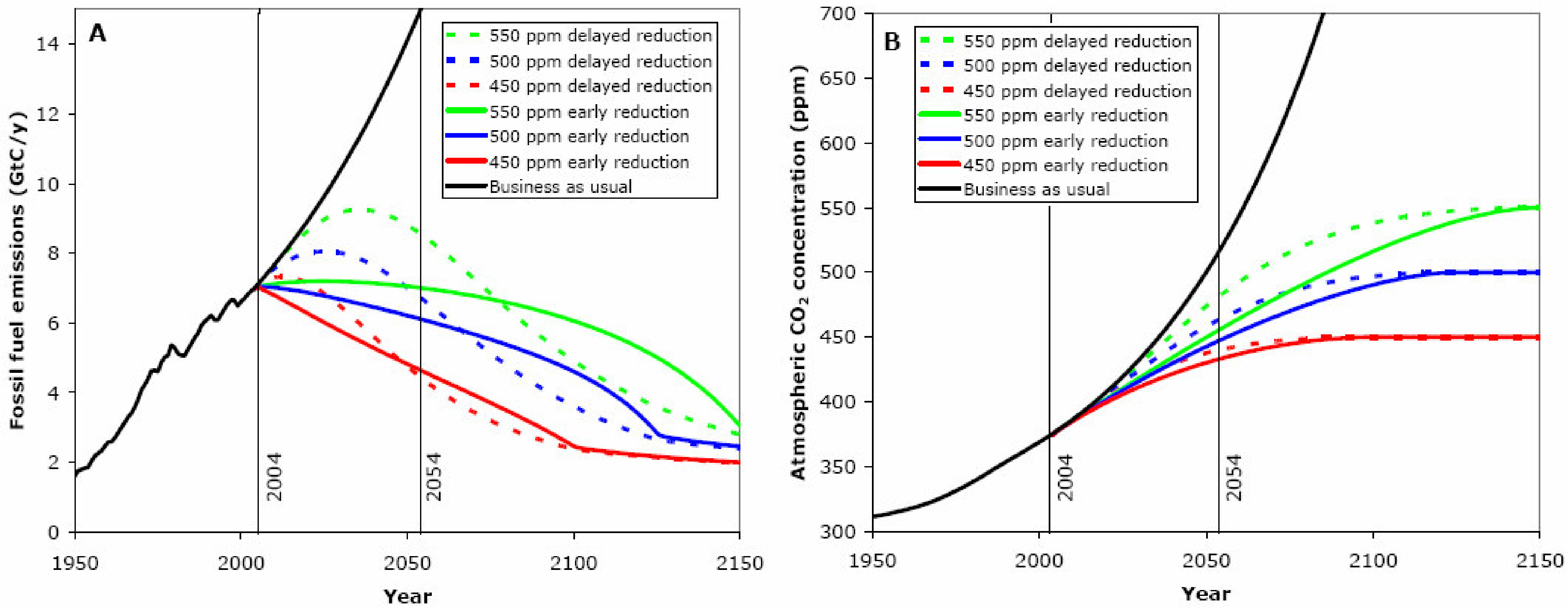
- $dC/dt = E - L - (C-C_0)/T$

- **For constant *E*, equilibrium at**
  - $C^* = C_0 + T(E - L)$

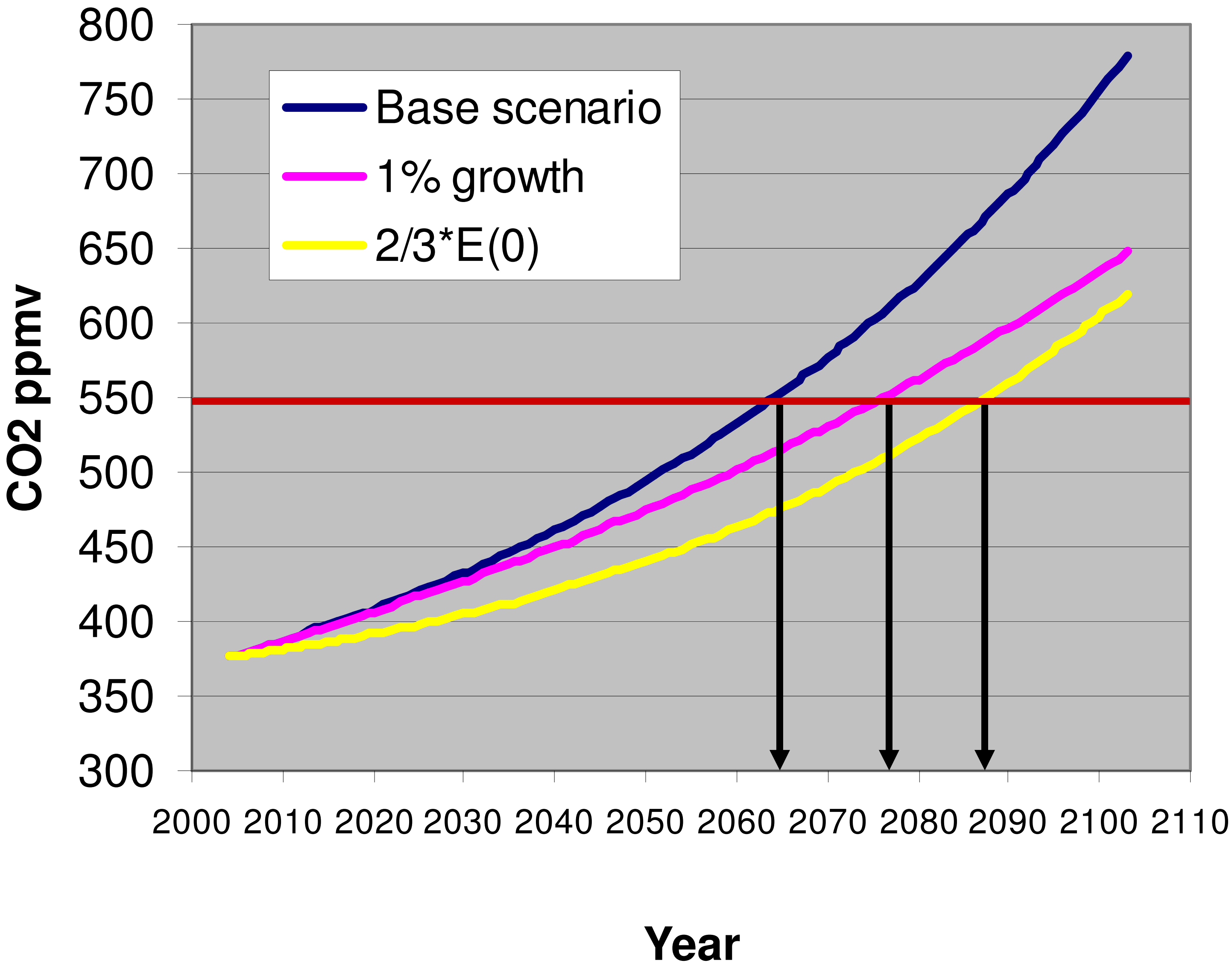
Lessons from the simple model

- **Equilibrium at C^* = 550 ppm implies E = 2.4 ppm/yr**
  - i.e., 20% below *current* emissions
  - C^* increases by 45 ppm for each decade of delay
- **The next century's emissions are cumulative because T = 100 yr**
  - Can emit more in short term, scale back harder long term

These features are evident in stabilization scenarios

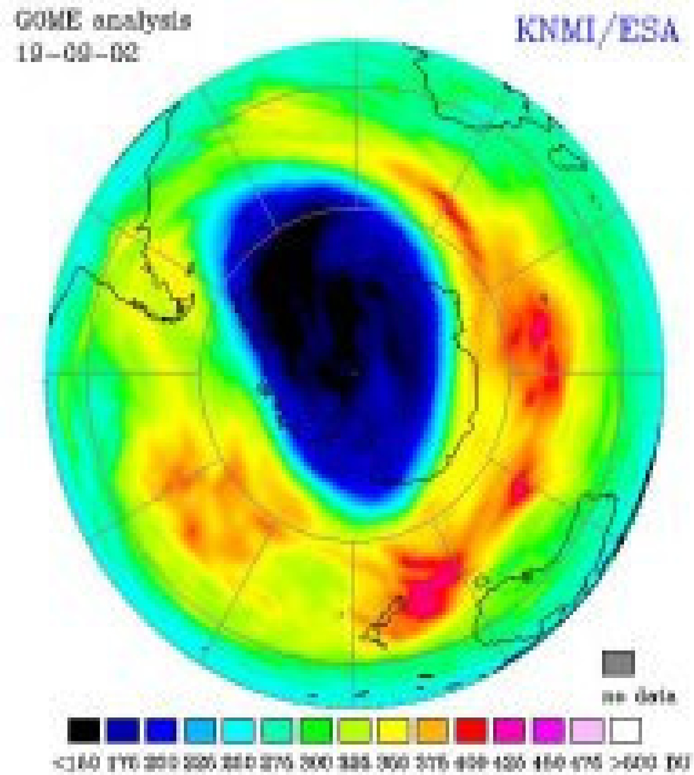


But modest emissions reductions only delay crossing the "danger" line



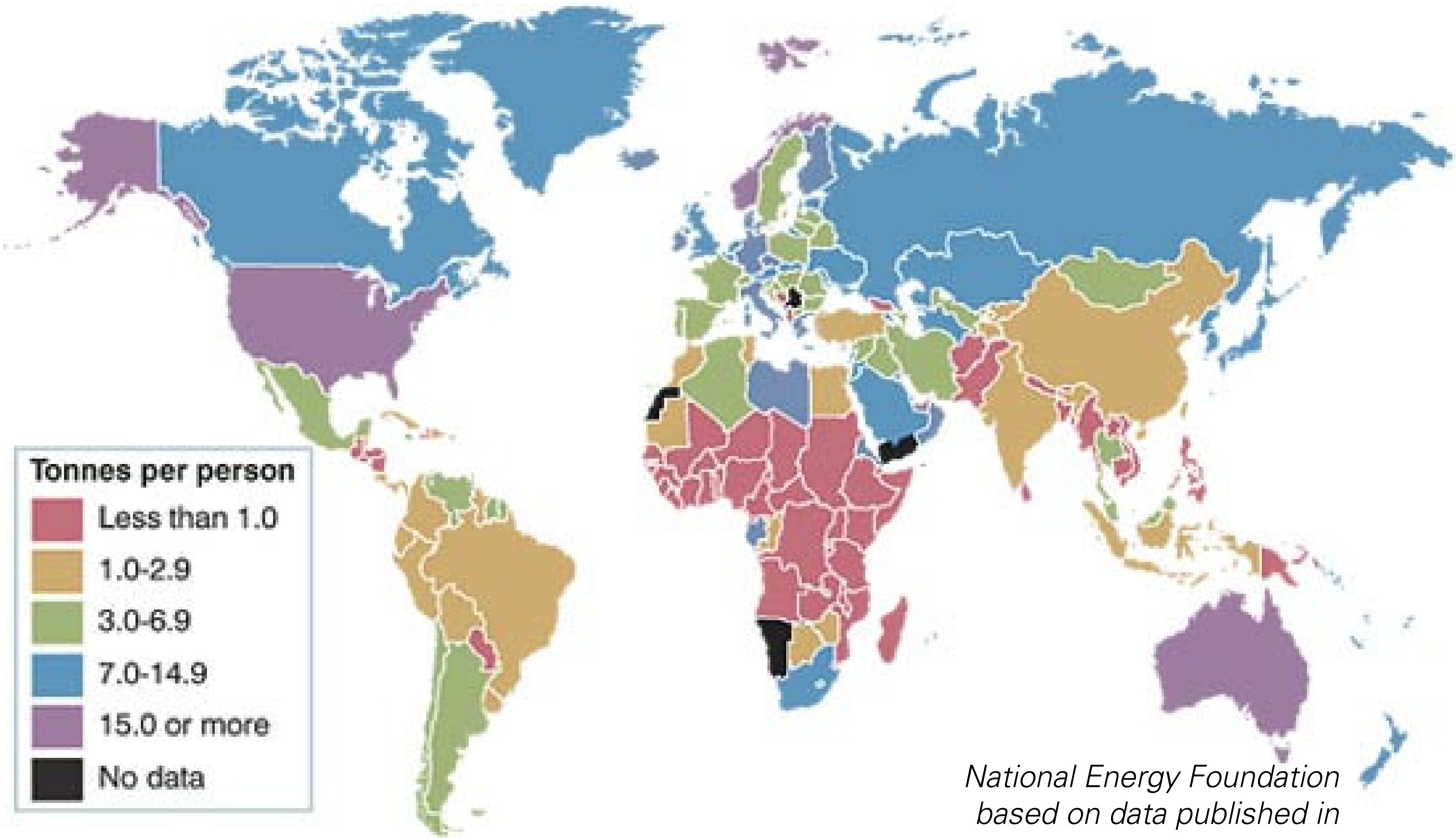
There are many social barriers to meaningful emissions reductions

- **Climate threat is intangible and diffuse; can be obscured by natural variability**
  - contrast ozone, air pollution
- **Energy is at the heart of economic activity**
- **CO_2 timescales are poorly matched to the political process**
  - Buildup and lifetime are centennial scale
  - Energy infrastructure takes decades to replace
    - Power plants being planned now will be emitting in 2050
    - Autos last 20 years; buildings 100 years
  - Political cycle is ~6 years
- **There will be inevitable distractions**
  - a few years of cooling
  - economic downturns
  - unforeseen expenses (e.g., Iraq, tsunamis)
- **Emissions, economics, and the perception of the threat vary greatly around the world**



CO2 Emissions per Person

Carbon dioxide emissions annual tonnes per person 2002



National Energy Foundation based on data published in New Scientist

Emissions heterogeneities

- **Emissions from the Developing World will be a major factor in this century**
  - DW emissions growing at 2.8% vs IW growing at 1.2%
  - DW will surpass IW during 2015 - 2025

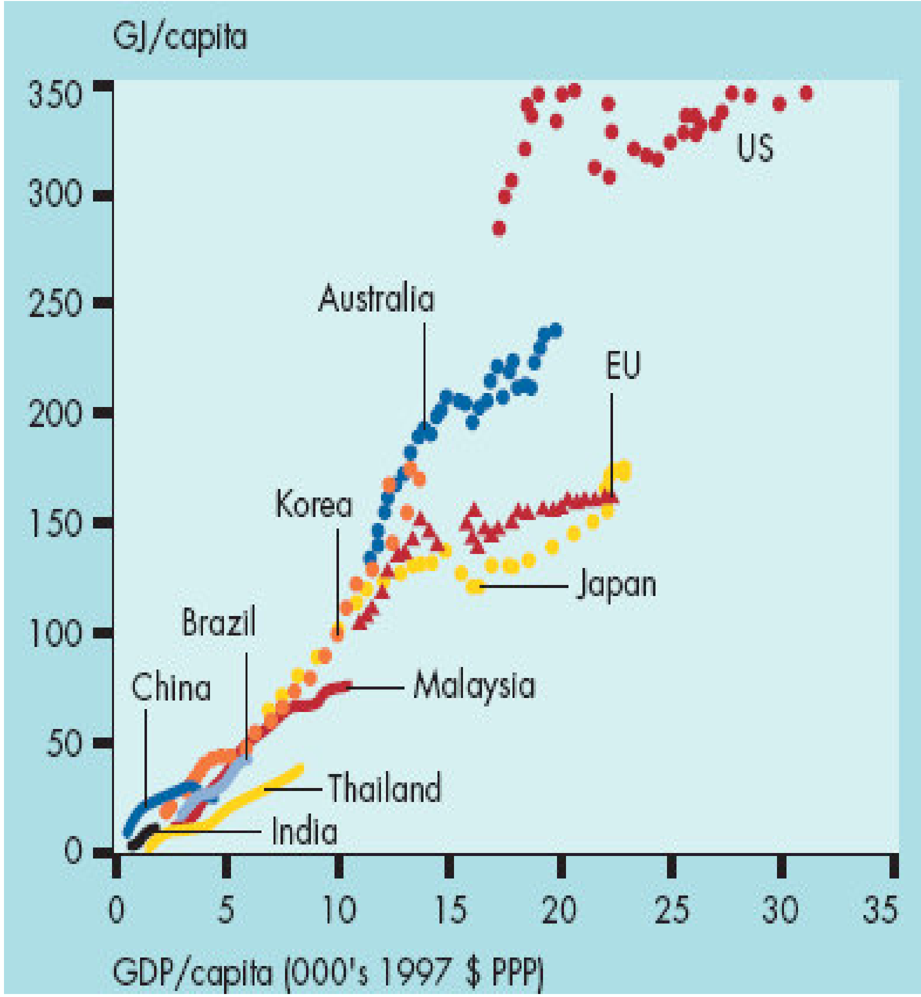
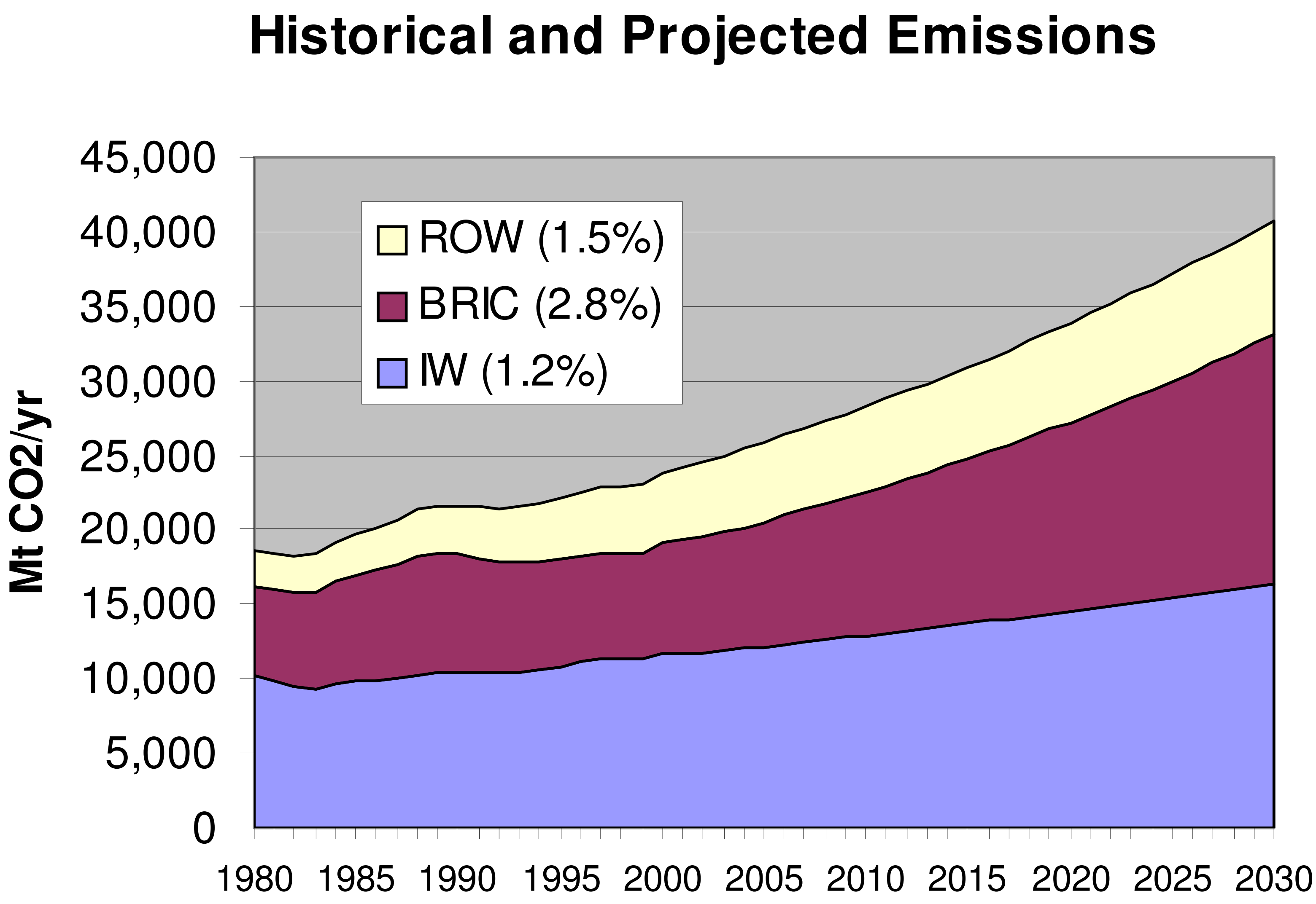
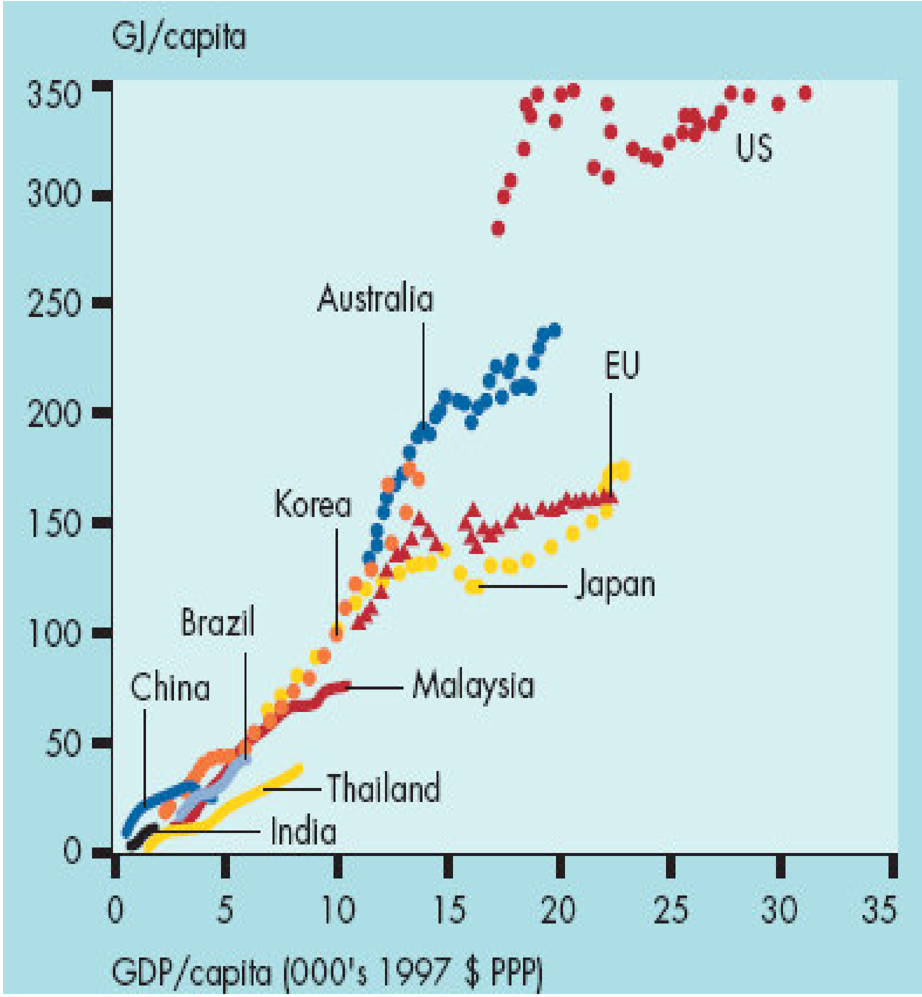


Illustration of the heterogeneity

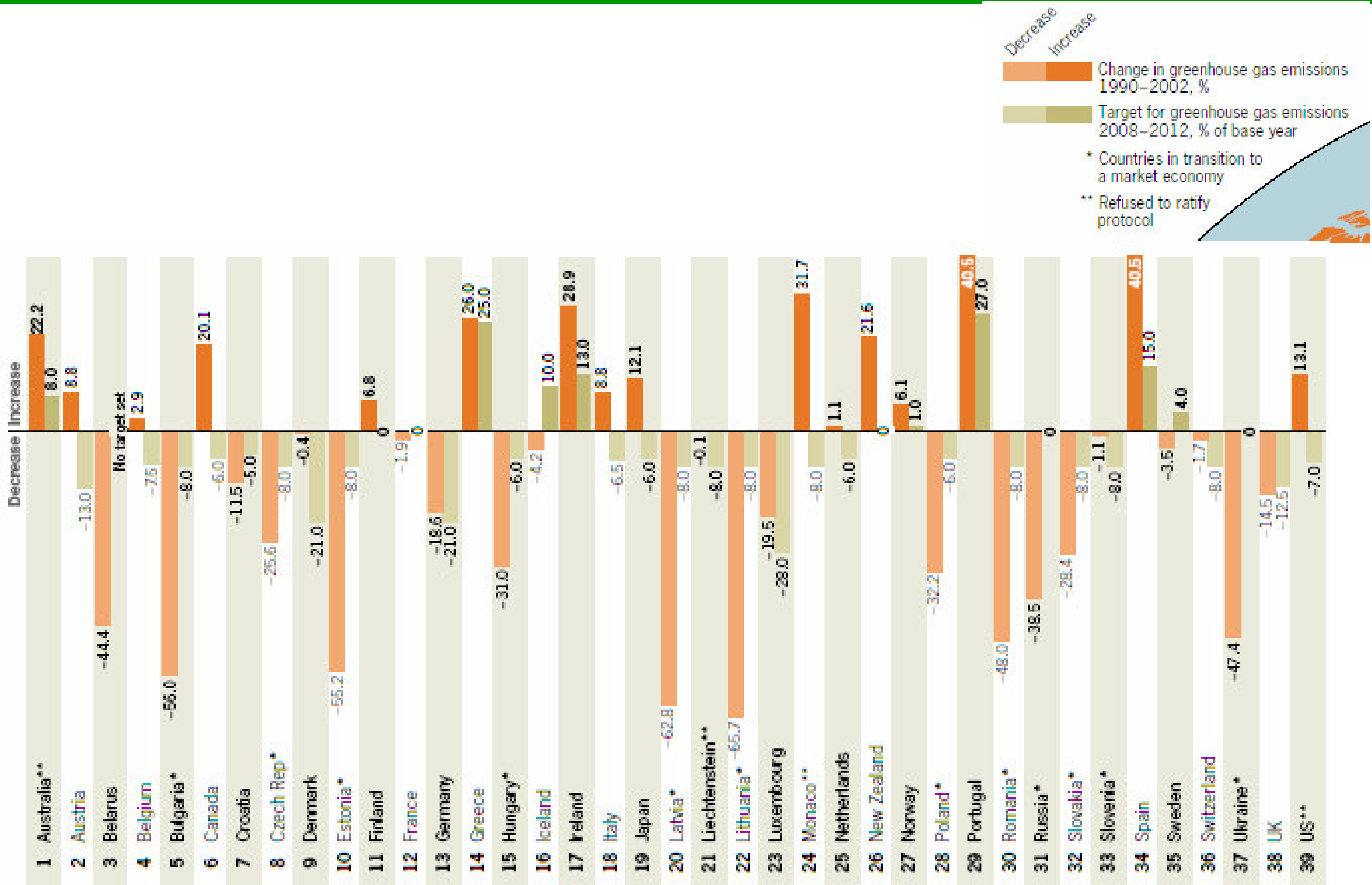


Emissions heterogeneities

- **Emissions from the Developing World will be a major factor in this century**
  - DW emissions growing at 2.8% vs IW growing at 1.2%
  - DW will surpass IW during 2015 - 2025
- **Sobering facts**
  - When DW ≥ IW, each 10% reduction in IW emissions is compensated by < *4 years* of DW growth
  - If China's (or India's) per capita emissions were those of Japan, global emissions would be 50% higher



How is the world doing on Kyoto?



Reducing GHG emissions entails direct costs

- **Steps to significantly reduce GHG emissions will entail new and specific costs**
  - If they didn't, they would be happening already
  - If they don't, why do countries / industries bicker over emissions quotas?
- **Fossil fuels are the cost benchmark**
  - Convenient, available
  - Carbon-free energy sources capable of having a significant impact are currently more costly, or unacceptable, or both
- **Efficiency can reduce emissions without cost, but only to a point**
  - Must not be negated by increased consumption
  - Incremental capital expense must not exceed expected operating savings

Who is going to pay?

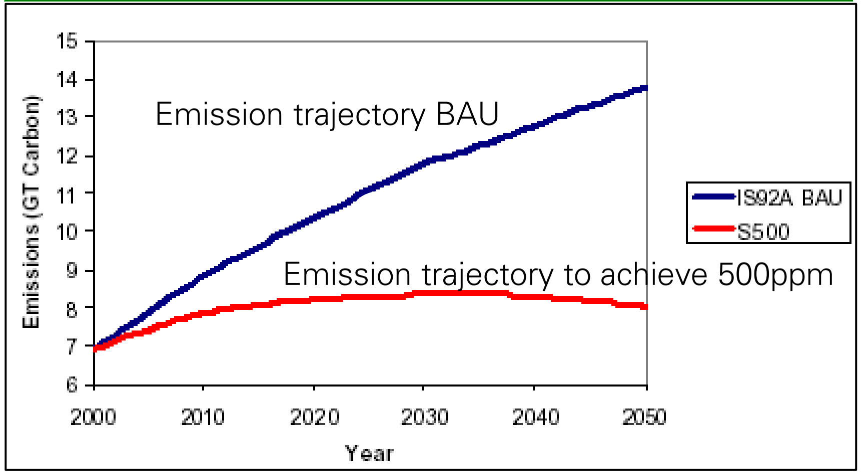
- The IW may assign a high priority to reducing its own emissions and be willing to pay the associated costs
- But the rest of the world has many more legitimate and pressing demands on their scarce resources
  – Local air quality, education, public health, food, transport, electrification, internal rich/poor disparity, …
- Global competition will be a barrier to the IW paying for the emissions-constrained growth of DW economies
  – DW economies will become larger than those of the IW
  – There will be competition for markets and resources (e.g., China in Brazil, Iran, Africa, Canada, …)

What might change this picture?

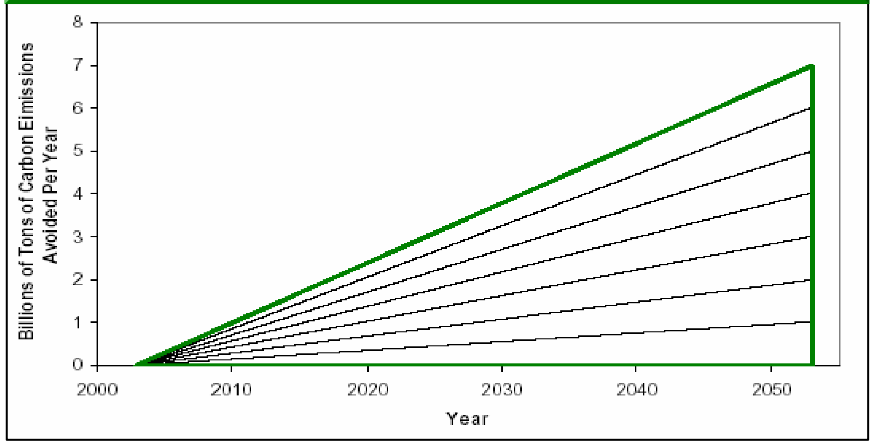
- A dramatic climate event that would galvanize the entire world to action, inducing the IW to pay for it all
- The development of cost-effective efficiencies and significant CO_2-lite energy sources <u>costing about the same as fossil fuels</u>
  - Allows all nations to moderate their emissions without compromising immediate self-interest.
- DW develops enough that CO_2 control rises in priorities
  - For China, GDP/cap \$3k $\rightarrow$ \$27k in 40 years at 5%/yr

Princeton 'wedges' demonstrate stabilization feasibility (but at a cost)

Emissions to 2050 for stabilisation



Seven Slices of the Stabilisation Wedge



Source: Princeton White Paper

Category	Wedge
Efficiency Improvements	Efficiency in energy conversion
	Efficiency in industrial processes
	Efficiency in buildings
	Efficiency in vehicles
Decarbonisation in Power	Gas substituting for coal
	Solar PV
	Wind
	Biomass
	Nuclear
Decarbonisation in Transport	Carbon free hydrogen
	Biofuels
Offsets	Capture and storage for power
	Capture and storage for transportation fuels
	Forestation
	Conservation tillage
Demand Management	Demand side management

15 Potential Wedges

Efficiency

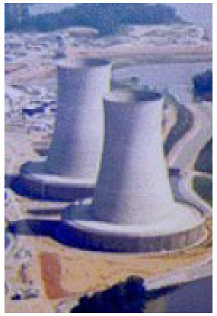
1. Double fuel efficiency of 2 billion cars from 30 to 60 mpg
2. Decrease the amount of car miles traveled by half
3. Use best efficiency practices in all residential and commercial buildings
4. Produce twice today's coal-based electric capacity with 50% greater efficiency

Fuel Switching

5. Replace 1400 coal electric plants with natural gas-powered facilities

Carbon Capture and Storage

6. Capture AND store emissions from 800 coal electric plants
7. Increase current hydrogen production from fossil fuels by a factor of 6 AND store the captured CO_2
8. Capture carbon from 180 coal-to-synfuels plants AND store the CO_2



Nuclear

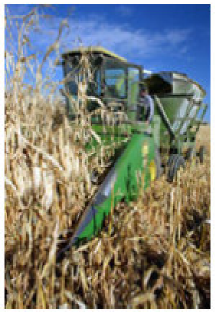
9. Add double the current global nuclear capacity to replace coal-based electricity

Wind

10. Increase wind electricity capacity by 50 times relative to today, for a total of 2 million windmills

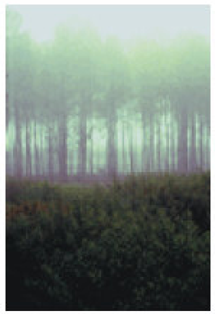
Solar

11. Install 700 times the current capacity of solar electricity
12. Use 40,000 square kilometers of solar panels (or 4 million windmills) to produce hydrogen for fuel cell cars



Biomass Fuels

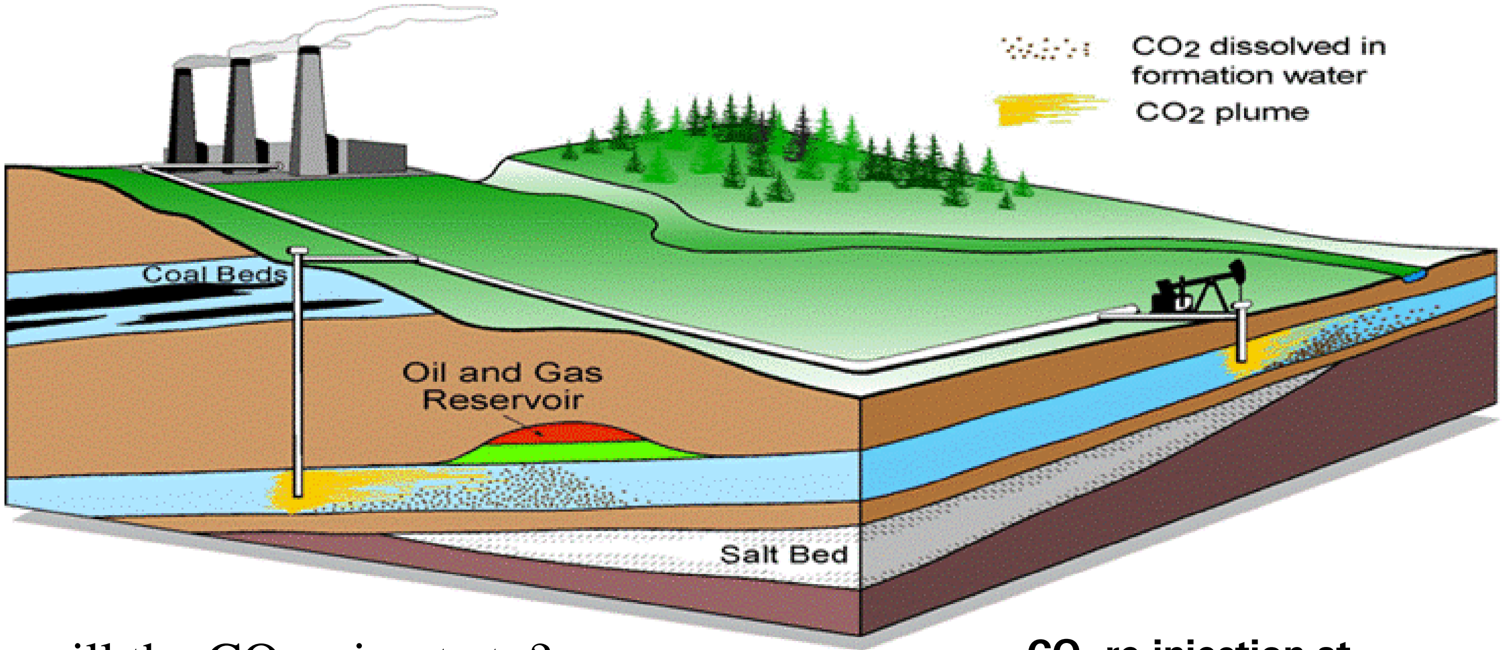
13. Increase ethanol production 70 times by creating biomass plantations with area equal to $1/6^{th}$ of world cropland



Natural Sinks

14. Eliminate tropical deforestation and increase the area of plantations on non-forested land by a factor of 6
15. Adopt conservation tillage in all agricultural soils worldwide

CO_2 capture & storage

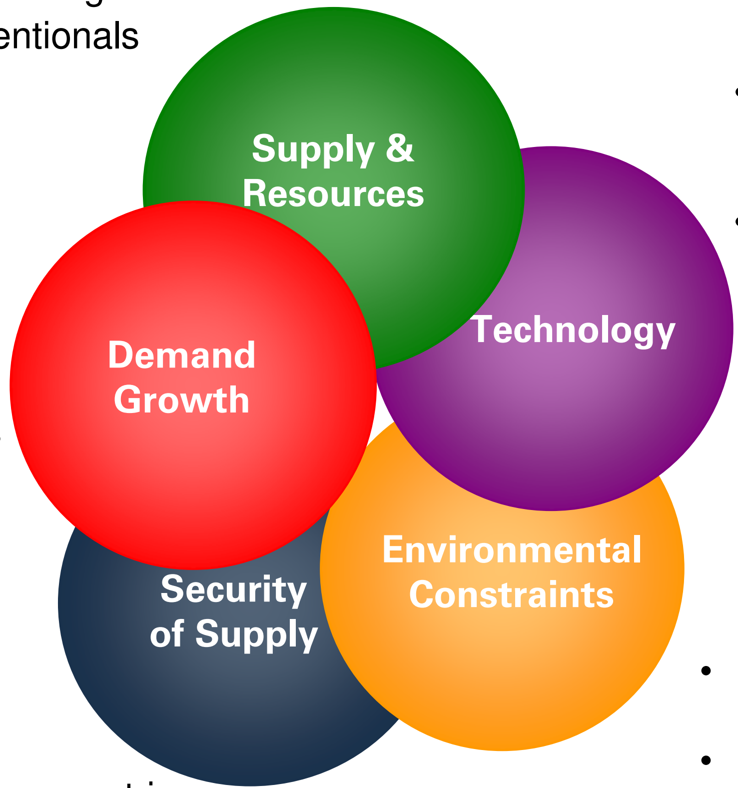


- Where will the CO_2 migrate to?
- Will the CO_2 stay down there?
  - need ~10^{-3}/yr leak rate
  - catastrophic release potential
- Integrity/Corrosion of the penetrations?
- Costs (currently ~ 30% increment to COE)
  - Mostly in the capture
  - Will always be incremental

CO_2 re-injection at the In Salah gas field

five key drivers of the energy future

- significant hydrocarbon resource potential
- misalignment between resource location and demand
- growing supply challenges
- growth of unconventionals



- **advances in all technology but especially info-tech, biotech and nanotech**
- **potential for breakthroughs in energy production, conversion or storage**

- rapid GDP growth esp. in developing countries
- growth of megacities
- changing customer preferences
- potential for demand side intervention

- climate change and potential for carbon constraints
- tightening of regulation relating to local pollution
- increasing scrutiny for extractive industries

- governance failures in producing countries
- significant rise in import dependence
- new policy initiatives to enhance energy security
- growing competition for energy resources

Examples of Potential Technologies

Primary Energy Sources:

- Light Crude
- Heavy Oil
- Tar Sands
- Wet gas
- CBM
- Tight gas
- Nuclear
- Coal
- Solar
- Wind
- Biomass
- Hydro
- Geothermal

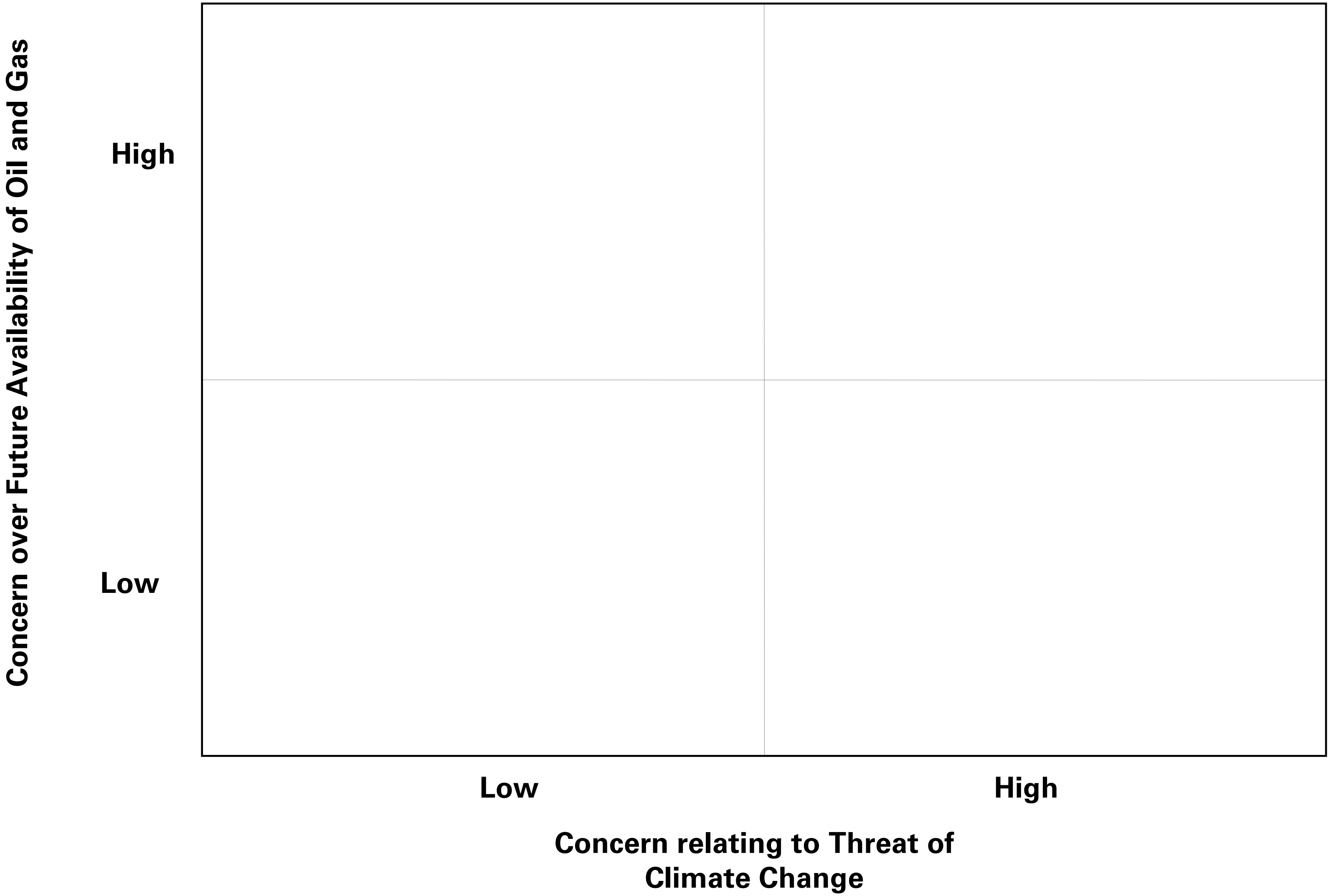
Extraction & Conversion Technologies:

- Exploration
- Deeper water
- Arctic
- LNG
- Refining
- Differentiated fuels
- Advantaged chemicals
- Gasification
- Syngas conversion
- Power generation
- Photovoltaics
- Bio-enzyimatics
- H_2 production & distribution
- CO_2 capture & storage

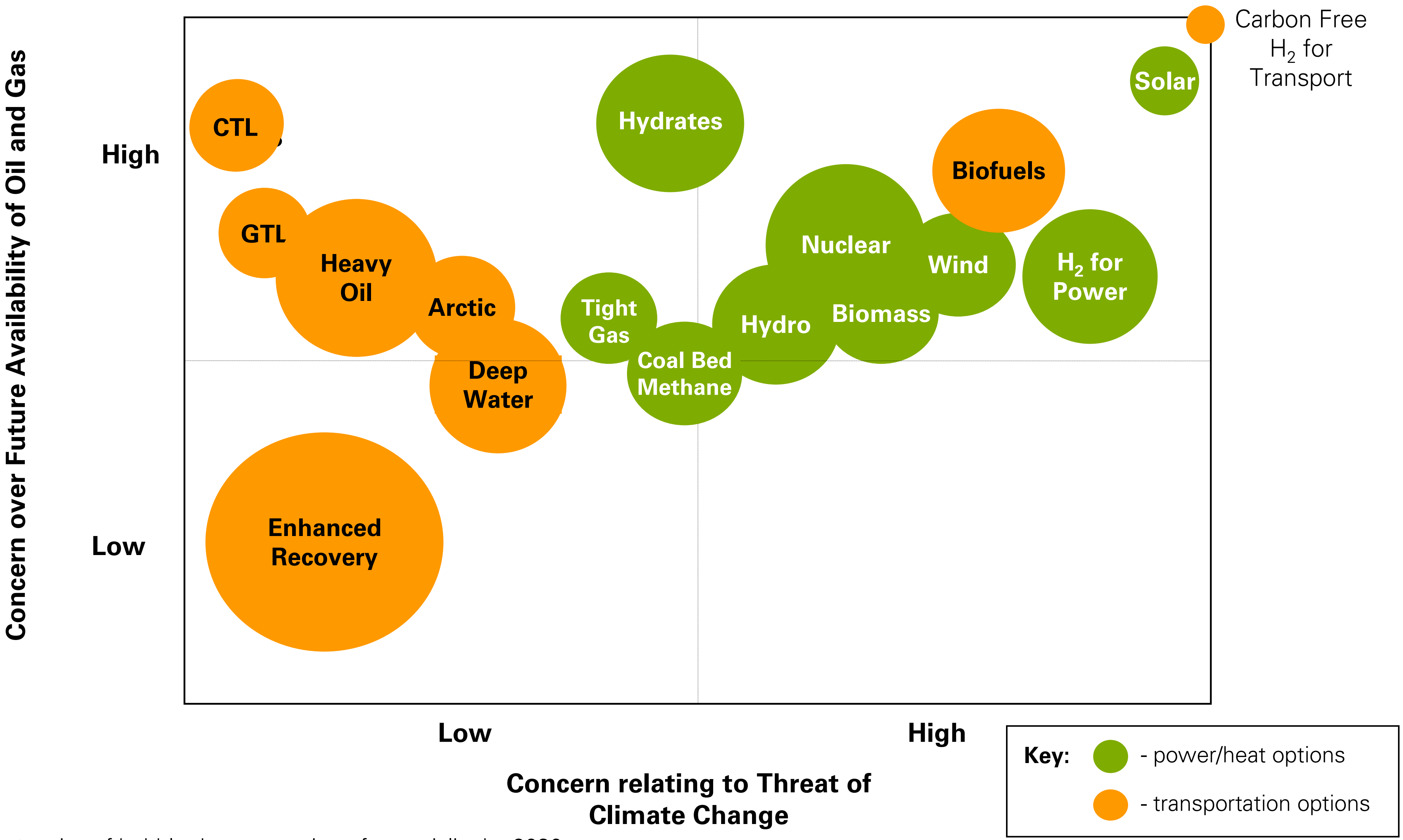
End Use Technologies:

- ICEs
- Adv. Batteries
- Hybridisation
- Fuel cells
- Hydrogen storage
- Gas turbines
- Building efficiency
- Urban infrastructure
- Systems design
- Other efficiency technologies
- Appliances
- Retail technologies

evaluating long term supply options

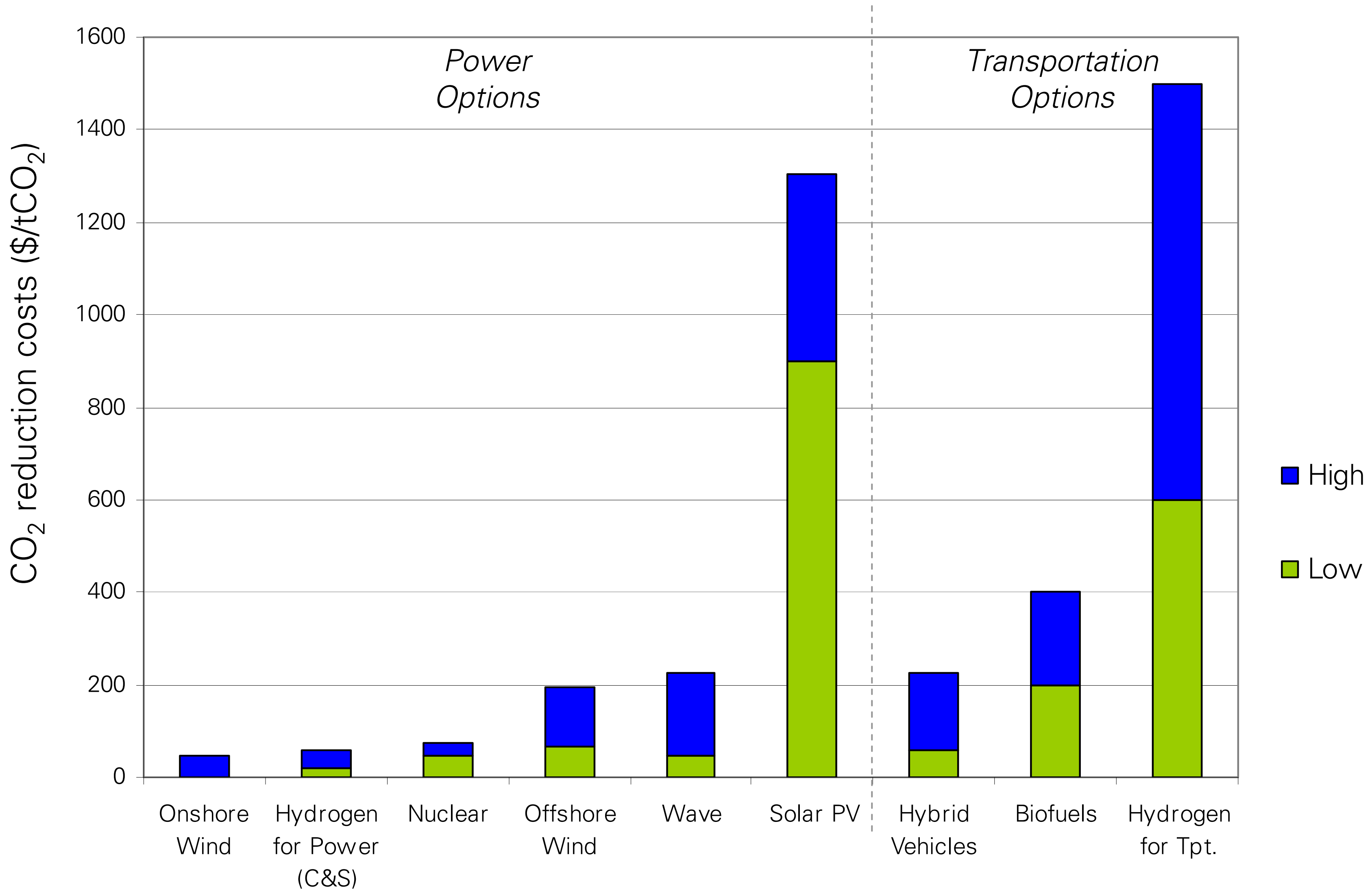


evaluating long term supply options



Note: size of bubble denotes notion of materiality by 2030

evaluating lower carbon technology options



Source: DTi (2003, Concawe, BP estimates

Take-home points for the next several decades

- Strong demand growth
- Adequate hydrocarbon resources
- Energy and Technology choices will be modulated by security and environmental considerations